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An analysis of information impacts in international currency markets.

Gordon Johnson
University of Massachusetts Amherst

AN ANALYSIS OF INFORMATION IMPACTS IN INTERNATIONAL CURRENCY MARKETS

A Dissertation

by

GORDON JOHNSON

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GORDON JOHNSON

Approved as to style and content by:

Thomas Schneeweis, Chair

Hossein Kazemi, Member

Nelson Lacey, Member

Bernard J. Morzuch

Bernard Morzuch, Member

Mark Kritzman

Mark Kritzman, Advisor

Ronald Karren, Ph.D. Program Director
School of Management

to Tracey

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ABSTRACT

AN ANALYSIS OF INFORMATION IMPACTS IN INTERNATIONAL CURRENCY MARKETS

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GORDON A. JOHNSON, B.S., CALIFORNIA STATE UNIVERSITY, HUMBOLDT

M.B.A., UNIVERSITY OF WASHINGTON, SEATTLE

PH.D., UNIVERSITY OF MASSACHUSETTS

Directed by Professor Thomas Schneeweis

A growing body of evidence has accumulated on the behavior of volatility for pricing data on a variety of different financial assets. Twenty-four-hour currency markets are a particularly useful vehicle for examining the relationship between information and asset volatility — in part because the distinction between public and private information is clearly defined in the foreign exchange market. This study provides a comprehensive examination of the effect of public news on inter- and intra-day exchange-rate return variances. Unlike previous studies, the impacts of <u>both</u> U.S. and foreign macroeconomic news announcements are examined in the spot <u>and</u> futures currency markets — for the yen, pound, and mark. The relationship between news and volatility is first examined using variance ratio tests over trading and non-trading periods. Second, diffusion and jump-diffusion process models are developed which contain parameters conditional on the release of news. These models are estimated using the method of maximum likelihood and are compared to equivalent unconditional models using likelihood ratio tests.

Results from this study provide insight into the relationship between public information and currency market volatility. Variance ratio tests indicate that U.S. news releases have a

greater impact on currency variance than foreign news releases. In addition, trading/non-trading variance patterns are found to differ between the spot and futures markets — particularly for the yen. Market liquidity differences and the timing of public news announcements are shown to be factors which can explain whether the spot or futures markets reflect the arrival of public information first. The impact of public macroeconomic news releases on volatility is also shown to be concentrated in the period immediately surrounding the announcement.

Maximum-likelihood estimation of diffusion and jump-diffusion process models reveals that simple models, conditional on *ex ante* macroeconomic news announcements, better explain the currency return generating process than equivalent unconditional models. Over the period studied, merchandise trade balance and industrial production announcements had a greater impact on volatility than money supply or inflation announcements. Finally, the correlation between the yen, pound, and mark was highest on days of U.S. macroeconomic news.

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CHAPTER 1

INTRODUCTION

A growing body of evidence has accumulated on the behavior of return variance for different types of pricing data — including stock prices, commodity prices, and exchange rates.[1] Several studies have shown that weekly, daily, and intra-daily exchange rate returns can be approximated by a martingale process.[2] However, a martingale is very general and says little about what is increasingly being found to be a more complex process. In particular, exchange rate returns have recently been shown to exhibit *volatility clustering* — i.e., large positive or negative returns tend to be followed by large returns (of either sign) and periods of tranquility tend to alternate with periods of high volatility. This time-varying volatility process has been hypothesized to be the result of an increased volatility of returns following the arrival of new information to the market. As a result, a number of authors have recently begun to model the conditional volatility of exchange rate returns as ARCH and GARCH processes to account for the arrival of news.[3] Several authors have shown that currency return variance differs over U.S. and foreign trading periods and have attributed this to the increased rate of release and importance of U.S. information.[4] However, only recently have studies focused on the impact of news on intra-day volatility patterns in currency markets for time periods in which <u>actual</u> macroeconomic releases are expected to occur.[5] In addition, the few studies that have focused directly on the actual macroeconomic informational responses have concentrated on the impact

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[1] Castanias (1979), French, Leftwich, and Uhrig (1989), French and Roll (1986), Hill, Schneeweis, and Yau (1990), Pearce and Roley (1985), Savanayana, Schneeweis, and Yau (1992).

[2] A stochastic process $\{\tilde{x}_t\}_0^t$ is a martingale with respect to the information in the stochastic process $\{\tilde{y}_t\}_0^t$ if $E[|\tilde{x}_t|] < \infty$ and $E[\tilde{x}_{t+1} | y_0, y_1, \ldots, y_t] = x_t$. Thus, x_t is a function of $y_0, y_1, \ldots, y_t$. In particular, it is the expected value of $\tilde{x}_{t+1}$. The martingale property can also be stated as ($\tilde{x}_{t+1} - \tilde{x}_t$) is a fair game with respect to $\{\tilde{y}_i\}_0^t$. The important property of martingales is that there is no expected change in the level of x over any interval. For more detail on martingale processes, see Ingersoll (1987) pp. 17-18.

[3] Baillie and Bollerslev (1990), Engle, Ito, and Lin (1990), Meese and Singleton (1982).

[4] Hertzel, Kendall, and Kretzmer (1990), Müller, *et al*. (1990).

[5] Ito and Roley (1987), Harvey and Huang (1991).

of information releases on a single currency (e.g., yen/dollar) or a single currency market (e.g., futures).[6] Only Ito and Roley (1987) examine the effect of foreign information (Japanese) as well as U.S. information.

Exhange rates have been shown to exhibit leptokurtosis (fat tails) in the distribution of daily returns.[7] Thus, modeling exchange rate returns as a simple diffusion process may be a misspecification of the process either because of the presence of discontinuities in the sample path of returns or the violation of the assumption of stationary parameters. Incorporation of a jump process into a model of exchange rate movements allows returns to be decomposed into *normal* and *abnormal* components. The normal portion consists of the usual day-to-day fluctuations. The abnormal portion, in constrast, is due to discontinuities the data — which may be related to the random arrival of important information. Jorion (1988) finds that exchange rates display jump components and that these discontinuities are still present even after allowance is made for volatility clustering by incorporating an ARCH process into the model. Therefore, an attempt to examine the effect of actual news releases on conditional volatility should include a jump process in the model of exchange rate returns to avoid using a misspecified model and failing to detect changes in volatility because of discontinuites present in the data.

The first goal of this study is to provide a comprehensive examination of the effect of macroeconomic news on intra-day exchange rate return variances. This goal is accomplished by examining the effect of U.S. and foreign macroeconomic information releases (i.e., industrial production, merchandise trade balance, inflation, and money supply) on trading and non-trading period variance ratios for the three major currencies (pound, yen, and mark) relative to the U.S. dollar in both the spot and futures markets. The second goal of this study is to gain a better understanding of the process exchange rate returns follow by incorporating jump processes and conditional variance terms into the return process specification. This is accomplished by

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[6] Ito and Roley (1987), Harvey and Huang (1991), respectively.
[7] McFarland, Pettit, and Sung (1982) and So (1987).

developing a variety of diffusion and jump-diffusion process models of exchange rate returns with additional variance terms conditional on information releases — and then testing them against a simple diffusion process model of returns.

1.1 Data and Methodology

The data for this study consists of daily Deutsche mark, British pound, and Japanese yen spot market rates and futures contract prices for the near-term yen, pound, and mark futures contracts traded on the Chicago Mercantile Exchange. The data series analyzed is for the three year period January, 1988 through December, 1990. For currency futures, the near-term U.S. currency futures contract is used and rolled over into the next position contract at the beginning of the delivery month. In addition, futures open and closing prices (8:20 a.m. and 3:00 p.m. Eastern Standard Time (EST)) were available only for U.S. trading sessions. The opening and closing prices for U.S. spot markets were obtained from Data Resources Incorporated and Bankers Trust. Spot currency prices used are 8:00 a.m. 12-noon, and 3:00 p.m. EST. Trading period returns are defined as the open-to-close log return in the U.S. market. For the spot market, trading-period returns are also partitioned into morning and afternoon sub-periods by using the 12 noon quote. Non-trading period (i.e., foreign trading period) returns are defined as the close-to-open log return. The news releases studied are four macroeconomic variables which have often been asserted to affect the distributional parameters of various financial assets, as well as exchange rates: (1) merchandise trade balance, (2) industrial production, (3) consumer price index, and (4) money supply. Finally, the release dates for these four macroeconomic releases and their corresponding foreign releases are collected for the U.S., Germany, Britain, and Japan.

For U.S. markets trading/non-trading period studies have been conducted in the cash as well as futures markets.[8] These studies have focused on differences in asset returns and

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[8] Castanias (1979), French, Leftwich, and Uhrig (1989), French and Roll (1986), Hill, Schneeweis, and Yau (1990), Pearce and Roley (1985), Savanayana, Schneeweis, and Yau (1992).

variances between weekdays and weekends, between overnight and business hours trading, as well as within intra-day trading hours. Results from these studies indicate greater return variance during trading periods than non-trading periods. Several hypotheses including market structure, information impacts, and noise trading have been advanced as explanations for the instability of trading/non-trading period volatility.[9] The information explanation for the variance differential over trading and non-trading periods is that volatility changes in response to the non-uniform arrival and assimilation of information across trading and non-trading hours.

1.2 Trading/Non-Trading Variance Ratio Results

In order to conduct a thorough examination of the impact of macroeconomic news on trading/non-trading period currency return variance patterns, the methodology of French and Roll (1986) is followed in this study. F-tests are computed as follows: *F-ratio = Var(trading period returns)/Var(non-trading period returns).* Computing F-ratios for various trading/non-trading periods conditional on the presence or absence of U.S. or foreign macroeconomic releases permits a number of hypotheses to be tested. For example, the F-ratio for trading period returns on days of U.S. information releases and non-trading period returns on days of no foreign information releases for each currency can be computed. Comparing this ratio to an equivalent ratio computed for days when neither U.S. or foreign information (for that currency) was released allows an examination of the impact of this study's specific set of macroeconomic releases on intra-day volatility.

Results from variance ratio tests indicate that for all three currencies studied, spot and futures exchange rate return variances differ between U.S. trading and non-trading periods. In addition, results for the Japanese yen are in agreement with work by Ito and Roley (1987) which indicates that Japanese macroeconomic information releases have a positive impact on currency variance during foreign trading periods (U.S. non-trading time) which is similar to, but

[9] Barclay, Litzenberger, and Warner (1990), French and Roll (1986), and Froot and Thaler (1990).

smaller, than the increase in U.S. trading period variance that occurs on U.S. macroeconomic release dates. However, while results for the British pound and Deutsche mark indicate an increase in foreign trading period variance on days of U.K. and German macroeconomic information releases similar to that for the Japanese yen, the increase in variance for both currencies is smaller than for the yen. Finally, after partitioning the U.S. spot market trading time into morning and afternoon sub periods, the variance impact of U.S. macroeconomic information releases is found to take place in the period immediately surrounding the information release.

1.3 Conditional-Variance Return Process Models Results

In order to further examine the relationship between conditional variance and the release of macroeconomic information, maximum likelihood estimation techniques and likelihood ratio hypothesis tests are used as means of estimating and then comparing various models of the currency return generating process. The methodology used follows that of Jorion (1988). In contrast to Jorion's work, however, intra-day rather than monthly and weekly currency returns are used and additional variance terms conditional on macroeconomic news releases are incorporated in the diffusion and mixed jump-diffusion process models being estimated. Variance ratio results from this study (as well as other authors' results) indicate that volatility patterns for currency returns differ across trading and non-trading periods. Thus, in this study return generating process models are estimated across trading and non-trading periods separately to enable a more focused examination of the impact of U.S. or foreign macroeconomic news on the relevant period's volatility.

A simple diffusion process model of exchange rate returns $\ln(x) = \mu + \sigma_1 dz$ is tested against a diffusion process with a second variance term ($\Phi\sigma_2 dz$) which is conditional on the release of one of the macroeconomic releases in this study: $\ln(x) = \mu + \sigma_1 dz + \Phi\sigma_2 dz$ (where Φ represents a zero-one dummy variable which takes on the value one if a macroeconomic release occurs during that period). Since the simple diffusion process model is nested in the conditional variance model, the ratio of log-likelihood values from maximum likelihood estimates of each model is distributed chi-square with degrees of freedom equal to the number of parameters (one in this case) restricted to equal zero in the simple model. Thus, the null hypothesis that the restricted (simple diffusion process) model is superior to the conditional variance model can be tested. In a similar fashion, Jorion's mixed jump-diffusion process model is extended to include a second variance term ($\Phi\sigma_2 dz$) conditional on the release of news, which can then be tested against the unconditional jump-diffusion process model which is nested in it. Likewise both the unconditional and conditional jump-diffusion models can be tested against the simple diffusion process model which is nested in both of them.

Results from maximum likelihood estimates of various models with and without conditional variance terms indicate that easily constructed models which incorporate readily available *ex-ante* information on the timing of macroeconomic news releases are superior to a simple random walk model of exchange rate returns. The results indicate that for a subset of the macroeconomic variables used in this study (i.e., merchandise trade balance and industrial production) a mixed jump-diffusion process with conditional variance parameter model of trading period returns is superior to a simple jump-diffusion process model. Further, although over the 1988-90 period U.S. merchandise trade balance and industrial production announcements had highly significant impacts on trading period variance, the other two variables, consumer price index and money supply, did not significantly impact trading period volatility. However, different variables could have an impact over different periods than the period used for this study.

The results from this study also indicate that while foreign macroeconomic releases had some impact on non-trading period returns, the impact was less than the impact of U.S. releases on trading period returns. For a diffusion process with a conditional variance term, foreign merchandise trade balance and money supply announcements had the most impact on the mark and pound non-trading period volatility — while none of the macroeconomic variables had a detectable impact on the yen. In contrast, for a mixed jump-diffusion process with conditional variance none of the variables affected the mark, pound or yen. These results suggest that different models may be required to detect the impact of foreign macroeconomic news announcements on non-trading period returns for different currencies.

1.4 Conclusions and Implications from this Study:

In summary, results from this study demonstrate that both U.S. and foreign macroeconomic releases contain information which affect the pattern of exchange rate return variances, although the impact of foreign releases is not as large. Not all macroeconomic variables, however, have been found to influence volatility. It may be that the effect of different variables changes over time as market participants redirect their focus to other variables. A simple diffusion process of exchange rate returns is rejected in favor of models which incorporate variance parameters conditional on macroeconomic announcements. In addition, a simple mixed jump-diffusion process model is rejected in favor of a mixed jump-diffusion model with a conditional variance parameter. Finally, it appears that different models may be needed to detect the impact of foreign macroeconomic announcements on non-trading period volatility.

One implication of these results is that simple models using readily available *ex ante* information about scheduled macroeconomic announcements outperform a random walk model of exchange rate returns. This points toward a predictable component of currency return variance which could prove useful to practitioners as they manage their currency positions on a day-to-day basis. These results could also be important for the pricing of currency options. In this study, the overall variance estimate when a conditional variance term is included is lower than the variance estimated with a simple diffusion process. Thus, on days of no macroeconomic releases, the standard deviation obtained using a conditional variance model will yield an option price with less of an upward bias.

CHAPTER 2

SURVEY OF RELEVANT LITERATURE

Recent years have seen an increasing interest in modeling the volatilities of price returns for various financial assets. From a financial economist's point of view, understanding and modeling volatility is important. First, investment decisions, as characterized by asset pricing theories, depend heavily on the assessment of future returns and risks of various assets. The estimated volatility (standard deviation) of a security return is widely used as a simple risk measure in many asset pricing models. Secondly, the expected volatility of a security return plays an important role in the theory of option pricing. For example, the standard deviation of a return series enters directly into the well-known Black-Scholes model. Finally, an adequate specification of return volatilities may shed some light on the generating process of the returns.

Empirical studies of the relationship between price volatility and news can be separated into two general categories. The first category consists of studies which either identify specific news releases or the periods during which the news releases generally occur, and then compare volatility across different periods — e.g., trading versus non-trading, or different hours of the day. The second category consists of studies which specify volatility as a linear or non-linear time series process. The results from these two methodologies for studying volatility are reviewed in this chapter. The link between information arrival and asset volatility is reviewed in Section 2.1. In Section 2.2 distributional characteristics of currency returns are presented. Section 2.3 presents results from trading/non-trading period studies of the impact of news on currency volatility. The results from specifying currency volatility as a time series process are reviewed in Section 2.4. In Section 2.5, a survey of jump process models of asset (and currency) movements is presented. In Section 2.6 a brief survey of the literature on the relationship between asset variance and trading volume is presented. Finally, Section 2.7 concludes the chapter with a brief summary of results as they apply to currency markets.

2.1 The Arrival of Information and Asset Volatility

An asset's volatility is generally measured by the variability (or standard deviation) of its returns. New information which is related to the asset of interest results in changes in expectations, which in turn lead to changes in prices. Because volatility is the product of unanticipated price movements, it is closely related to information. In fact, price volatility can be thought of as simply the manifestation of information in the market. If new information never arrived to cause a reevaluation of market prices, prices would generally evolve in a smooth fashion. Another source of volatility is the trading brought about by the liquidity and asset allocation needs of institutions and the market-timing decisions of investors. Both of these can be thought of as the result of information — although private in nature, and thus difficult to monitor in the way that is possible for public information. However, the frequency with which public information arrives in the market, its average impact, and the time it takes the market to adjust to it can all be analyzed. In order to carry out an analysis of the impact of new information it is necessary to exploit several characteristics of information arrival. First, information arrives in discrete units or *packets* and the probability of its arrival is a function of time. Second, different pieces of information have different levels of content and, therefore, different effects on market volatility. Third, once information arrives it takes time for the market to *digest* or process it fully.

The public information that affects asset prices comes primarily from economic and financial announcements. Examples of economic announcements include the release of figures for inflation, money supply, gross national product, or trade balances. Examples of financial announcements include the release of a corporation's earnings figures or a dividend announcement. The extent to which the numbers contained in such announcements differ from expected values can be used as a gauge of the information content of the announcements. In addition, the types of public information mentioned above are conveniently measurable. Their arrival and the expected values — obtained either through consensus forecasts or through time series regressions on past values of the same or other variables — are easily monitored and quantified. However, the timing and impact of other sources of information, such as surprise political events (e.g., wars, assassinations, or terrorist attacks) or natural phenomena (e.g., earthquakes, floods, or droughts), are not as easily anticipated or quantified. But, their overall effect is not very pervasive either.[1]

A number of studies have examined the behavior of price return volatility in the cash and futures markets for various assets.[2] These studies focused on differences in asset return variance between weekdays and weekends, between overnight and business-hours trading, and across intra-day trading time hours. The results from both the spot and futures markets indicate that return variance during trading periods is greater than during non-trading periods. Various hypotheses have been advanced as explanations for the difference between trading/non-trading period volatilities — including market structure, information impacts, and noise trading.[3]

The information explanation for differences between trading/non-trading period variance is that volatility changes in response to the non-uniform arrival and assimilation of information across trading and non-trading periods. Brown, Harlow, and Tinic (1988) propose the *uncertain information hypothesis* as a means of explaining the response of rational, risk-averse investors to the arrival of unanticipated information. The hypothesis predicts that following the release of news, short-run price movements can exhibit increased volatility while uncertainty about the full impact of the news is being resolved. Similarly, French and Roll (1986) concentrate on the process which information releases follow to explain the pattern of return volatility. They propose three reasons for the proportionally greater variance during a security's trading period: (1) public information is more likely to be released during normal

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[1] Cutler, Poterba, and Summers (1989) examined the relative impacts of macroeconomic news and *qualitative news* (e.g., political events) on stock price movements. They found that their macroeconomic news proxies explained about one-third of the variance of monthly stock index returns. However, their results cast doubt on the view that *qualitative news* can account for all the return variation that cannot be traced to maroeconomic news innovations.

[2] See Chiang and Tapley (1983) for an analysis of day of the week effects, Rogalski (1984) for a trading/non-trading time analysis of the day of the week effect, and Cornell (1985) for weekly patterns in asset prices. Also see Hill *et al*. (1990) for an analysis of trading/non-trading period variance patterns.

[3] See Makhija and Nachtmann (1989), Barclay, Litzenberger, and Warner (1990), French and Roll (1986), Froot and Thaler (1990).

business hours, (2) private information is more likely to be acted on primarily during periods of low transaction costs (e.g., trading hours), and (3) pricing errors, induced by noise trading, may be larger during trading time hours.

The relationship between trading and non-trading period variance cannot be easily modeled on an *ex ante* basis since each trading session is impacted by the unique information set available during that time period. Thus, a security's volatility pattern is not a strict function of trading/non-trading time, but rather of information arrival and the uncertainty surrounding the expected impact of that information. For example, Savanayana *et al.* (1992) show that for U.S. Treasury Bond futures (which trade approximately 24 hours a day) the impact of British and Japanese macroeconomic information releases on U.S. non-trading period variance is not as pronounced as the impact of similar U.S. macroeconomic information releases on trading period variance.

The differential impacts of U.S. versus foreign macroeconomic information may be related to the relatively greater size — and hence, presumably, the importance — of U.S. financial markets and the U.S. economy. For example, Geman *et al.* (1991) find that the volatility of returns for a foreign security (i.e., French Notional futures contracts) may be greater during the foreign country's non-trading period than during its own trading period — which they attribute to the impact of U.S. news releases.[4] They find, however, that French macroeconomic releases affect the volatility of assets traded in the French market in a manner similar to — but with less magnitude than — the effect of U.S. macroeconomic releases on the volatility of assets traded in the U.S. market. Harvey and Huang (1991) argue that we should expect volatility to be concentrated during the times when the most relevant news is concentrated. Thus, if U.S. macroeconomic news is considered to be more relevant than French macroeconomic news (because of the relative size of the two economies and their financial markets) then the greater volatility during the U.S. trading period compared to the French trading period is consistent

[4] Geman *et al.* studied the French Notional futures contract, which is a contract on bonds issued by the French government and is traded only in France during French business hours.

with the hypothesized relationship between the concentration of news and volatility clustering.

Pearce and Roley (1985) provide further evidence on the close relationship between macroeconomic news and asset prices. They find that macroeconomic variables which often contain surprises will also often (on average) move stock prices. Thus, the market appears to anticipate that some announcements are more likely than others to have significant information content and focus more closely on those releases. In addition, Pearce and Roley find that the effect of macroeconomic news related volatility is concentrated on the day of the announcement. Further, it appears that markets tend to rely on economic news announcements made by various governmental agencies. For example, Schwert (1981) determine that the stock market reaction to releases of the consumer price index occurs at the time of the announcement, approximately one month after the data are collected by the Bureau of Labor Statistics. In addition, the market's reliance on economic news announcements can change over time. Urich and Wachtel (1981) found that interest rates responded quickly to money supply announcements. However, they found that the market reaction was largest when policy makers emphasized the importance of the monetary aggregates.

Jain (1988) provides results which demonstrate that not only do prices react very quickly to any surprise in macroeconomic announcements, but that market participants do not differ substantially in their interpretations of the implications of the surprise. Jain examines the impact of macroeconomic announcements on hourly stock returns and trading volume. Jain finds that the effect of macroeconomic surprise on stock prices is reflected in a short period of one hour or so. If market participants agree on the effects of macroeconomic announcements, they may not engage in additional trading. Jain finds, however, that trading volume is not affected by macroeconomic surprise — a result consistent with the hypothesis that market participants interpret surprises in announcements in an analogous manner and do not engage in additional trading.

In summary, the results obtained from markets for assets other than foreign exchange indicate that there is a definite relationship between changes in volatility and the arrival ofinformation. Specifically, public news announcements in the form of macroeconomic releases have been found to have a significant impact on the nonstationarity of asset volatility in the period immediately surrounding the announcement.

2.2 Distributional Characteristics of Foreign Exchange Returns

Several studies have examined the distributional properties of foreign exchange spot rates and found some of the moments to be nonstationary over time. McFarland, Pettit, and Sung (1982) find that U.S. dollar denominated log returns for the major western currencies over daily intervals have a non-normal, but stable distribution. However, they also find that returns are high on Monday and Wednesday, but low on Thursday and Friday and conclude that daily currency returns do not conform to a simple process. So (1987) examined the same currencies and found them to exhibit skewness. On Thursdays the pound has significant negative skewness and the yen has significant positive skewness. The peseta and krona in turn exhibit their highest levels of positive skewness on Tuesdays and Wednesdays. Thus, there is evidence which suggests nonstationarity exists in exchange rate data and that the underlying distributions may change over time.

2.3 Trading/Non-Trading Time, News, & Currency Volatility

Researchers have recently begun to examine the patterns in currency volatility across trading and non-trading periods. The overall results which have emerged from these studies are that, like previous results for other assets, the variance of both spot and futures currency returns are greater during U.S. trading periods than during non-trading periods. For example, Meese (1986) found that the hourly variance[5] for the U.S. dollar/yen spot exchange rate during

[5] Hourly variance, when the price data is collected for periods longer than one hour, is simply the variance divided by the number of hours in the return period measured. This adjustment is explained in more detail in Section 3.2 in Chapter 3.

the New York trading period was about three times greater than during the non-trading period. Hertzel, Kendall, and Kretzmer (1990) examined currency futures contracts on the five major U.S. dollar-denominated exchange rates.[6] To test for the impact of news, Hertzel, Kendall, and Kretzmer exploit the fact that there are different degrees of overlap between the foreign business hours for each currency studied and the CME futures trading period. They find that: (1) hourly return variances are greater during trading-time than during non-trading time, (2) hourly return variances are greater during weeknight non-trading time than during weekend non-trading time and (3) the trading/non-trading time variance ratios are generally highest for the Canadian dollar contracts, lower for the European currency contracts, and lowest for the Japanese yen contracts. They conclude that the evidence supports the view that futures returns are influenced by public information released primarily during business hours.

Baillie and Bollerslev (1990) examine volatility in different market locations around the globe through hourly spot currency quotes for a six-month period in 1986. They find the U.S. market on average the most volatile, the European market second most volatile, and the Asian market least volatile. In addition, they find that hourly patterns in volatility are remarkably similar across the four major currencies. Specifically, increased volatility is found to occur in the period immediately surrounding the opening of the London and New York markets — with a similar, but much smaller, increase associated with the opening of the Tokyo market. Baillie and Bollerslev speculate that this phenomenon may well be due to a U-shaped pattern of trading, where heavy trading occurs at the beginning and near the end of the trading day — which suggests that the different currency markets may not be fully integrated. For instance, under a scenario where intra-day trading is dominated by market makers — many of whom hold open currency positions in their local market during the day, but only rarely overnight — trading volatility might be concentrated at the opening and closing of each market

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[6] Hertzel, Kendall, and Kretzmer examined dollar-denominated currency futures contracts for the five major currencies (e.g., highest volume) — which are the British pound (BP), Deutsche mark (DM), Japanese Yen (JY), Canadian dollar (CD), and Swiss franc (SF) — over the 1978-87 period.

location.[7] This distinct pattern is consistent with the models of Admati and Pfleiderer (1988) and Kyle (1985), where traders with diverse information find it optimal to exploit their private information at times when other traders are also active. However, Baillie and Bollerslev also note that "the increase in volatility around the openings of the major markets might also be related to the systematic release of news at that time."

Harvey and Huang (1991) attempt to establish a closer link between exchange rates and public information. They use open and close prices from the London and Chicago futures markets for the five major currencies to partition the 24-hour day into four periods.[8] They find higher exchange rate volatilities during U.S. trading hours for dollar-denominated exchange rates. However, they find higher volatilities during non-trading hours for cross exchange rates between European currencies. Harvey and Huang interpret these findings as evidence that U.S. information releases have a greater impact on exchange rates than foreign information releases. They also collect release dates for eight major U.S. macroeconomic announcements and break the distribution of these eight announcement down by day of the week. Using transactions data from the CME contracts, they analyze volatility over hourly intervals during the U.S. trading period. They find that volatility generally tends to be high at midday. On Fridays, however, the pattern is reversed and volatility is highest during the first hour of trading. They attribute the high Friday opening volatility to the release of three macroeconomic announcements they consider to be important — and which are always released on Friday mornings.[9] Thus, although Harvey and Huang conclude that the higher currency

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[7] Other authors have found that the variability of U.S. stock returns within a day also tend to have the distinctive U-shaped pattern. See, for example Wood, McInish, and Ord (1985) and Lockwood and Linn (1989).

[8] Harvey and Huang use hourly CME currency futures price data over the eight year period 1980-88 and from the London International Financial Futures Exchange (LIFFE) over the period 1986-87. Thus, the period where they are able to partition the 24-hour day into four trading and non-trading periods covers just the 1986-87 period. They are, however, able to partition the U.S. trading period on the CME into hourly sub-periods over the entire 1980-88 period.

[9] The macroeconomic announcements which they consider to be important are: civilian unemployment, producer price index, and capacity utilization. Harvey and Huang do not test to see whether or not the announcements actually cause the volatility. They simply note that there is high Friday opening volatility when these variables tend to be released. They do note that a number of other announcements may contribute to the Friday opening volatility. This seems likely since one or more of these three variables may be released simultaneously in some months, which would imply that high opening variance on the other Fridays in those months would have to be related to other variables which are not always released on Fridays.

market volatility for certain trading periods is most likely driven by the release of macroeconomic news on those days, they fail to statistically test that hypothesis.

Ito and Roley (1987) examine the relationship between surprises in U.S. and Japanese macroeconomic announcements and the dollar/yen spot exchange rate.[10] They divide each 24-hour period into *Tokyo*, *European*, *New York*, and *Pacific* segments. The hourly variance was lowest during the Pacific segment, a finding which they attribute to the low rate of information arrival during those hours. Ito and Roley define the surprise for a particular macroeconomic announcement as the difference between the actual release and the expectation for that release. Expectations were formed using a model which combined consensus forecasts with forecasts obtained from a time series regression. They found similar increases in variance in the New York trading period due to *ex post* surprise in the U.S. macroeconomic announcements and in the Tokyo trading period due to *ex post* surprise in Japanese macroeconomic announcements. However, their results indicate that the impact of U.S. announcement surprise had a greater impact on volatility.[11]

In summary, results from trading/non-trading time and hourly returns for both spot and futures currency markets indicate that the greatest volatility is associated with the time periods which are most likely to have the highest rate of information arrival. Moreover, there is a documented association between the arrival of macroeconomic news and currency volatility. More specifically, on an *ex post* basis, currency markets have been found to react to the surprise component of various macroeconomic releases. In addition — for the Japanese yen — U.S. announcement surprise had a greater impact on volatility than did surprise for equivalent foreign releases.

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[10] Ito and Roley examine the impact of surprise in macroeconomic news announcements — money supply, industrial production, and producer price index — on volatility in the dollar/yen spot exchange rate market over the period 1980-85.

[11] Ito and Roley found that U.S. money supply announcements had the most consistent effects.

2.4 Time Series Analysis of Currency Volatility

Widespread use of time series models to analyze the volatility patterns of asset prices began almost immediately after the publication of Engle's (1982) groundbreaking autoregressive conditional heteroskedastic (ARCH) model. In subsequent studies, the ARCH model has been shown to provide a good fit for many financial return time series.[12] The key feature of the ARCH model is that it imposes an autoregressive structure on conditional variance, which allows volatility shocks to persist over time. This persistence captures the tendency of returns of like magnitude to cluster in time and can explain the well documented nonnormality and nonstability of moments for empirical return distributions.[13]

Many researchers have employed variations and extensions of Engle's ARCH process to model variance nonstationarity — e.g., the generalized ARCH (GARCH) model of Bollerslev (1986), and the exponential GARCH (EGARCH) model of Nelson (1991).[14] An appealing explanation for the presence of an ARCH process in a return series is based on the hypothesis that daily returns are generated by a mixture of distributions, in which the stochastic rate of information flows into the market constitutes the mixing (or weighting) variable between the distributions. Bollerslev's GARCH model incorporates such a mixing variable. Thus, the error term in the GARCH model is drawn from a mixture of distributions, where the variance of each distribution depends upon information arrival over time. Lamourex and Lastrapes (1990) exploit the implication of the mixture model that the variance of daily price movements is heteroskedastic, and positively related to the rate of daily information arrival. They use daily trading volume as a proxy for the common stock mixing variable, and find that the ARCH effects tend to disappear when volume is included as an explanatory variable in the conditional variance equation. Thus, GARCH time series models may be capable of capturing the effects of news, but are not able to specifically identify the source or nature of the news.

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[12] For recent examples, see Bollerslev (1987), Lamoureux and Lastrapes (1988), Baillie and Bollerslev (1989), and Lastrapes (1989)

[13] See Fama (1965)

[14] The number of papers utilizing these models is too numerous to list here. See Bollerslev, Chou, and Kroner (1992) for a review of work in this area.

Recently, several authors have used ARCH and GARCH models to describe the observed volatility clustering in exchange rate returns. Specifically, exchange rates exhibit volatility clustering so that large positive or negative returns tend to be followed by large returns (of either sign) and periods of tranquillity tend to alternate with periods of high volatility. Engle, Ito, and Lin (1990) argue that the explanation for such volatility processes must lie either in the arrival process of news or in market dynamics in response to the news. Thus, if information comes in clusters, then currency returns may exhibit ARCH behavior even if the market perfectly and instantaneously adjusts to the news. Alternately, if the currency market is characterized by traders with diverse information sets, then insider/private information may be gradually disseminated into prices according to a market dynamics model such as the continuous auction equilibrium of Kyle (1985). Thus, volatility spillovers from one currency market to the next — a finding consistent with a failure of strong-form market efficiency — would be consistent with the market dynamics explanation of volatility clustering.

Engle, Ito, and Lin (1990) attempt to shed some understanding on whether volatility clustering in the currency market is due to the arrival process of news or to market dynamics. Using meteorological analogies, they hypothesize that news follows one of two processes. Suppose news follows a process like a *heat wave* so that a hot day in New York is likely to be followed by another hot day in New York but not typically by a hot day in Tokyo. The heat wave hypothesis is consistent with the view that a large news-induced shock to the currency market increases the conditional volatility but only in that country. Thus, if a new piece of news arrives at the end of the business day in New York, the conditional volatility of the New York currency market will increase on day $t+1$, but not the conditional volatility of the intervening Tokyo or European markets. The alternate analogy is a *meteor shower* which rains down on the earth as it turns. A meteor shower in New York will almost surely be followed by one in Tokyo. The implication of the meteor shower hypothesis is that a news-induced shock to the currency market at the end of the business day in New York will result in an increase in the conditional variance of the following market session in Tokyo, and possibly Europe.

Engle, *et al.* (1990) use nested GARCH models and likelihood ratio tests to compare world-wide 'news' models which allow cross-country 'news' autocorrelations.[15] They examine Japanese yen spot market prices over the 1985-86 period and divide the 24-hour day into the same four major market segments as in Ito and Roley (1987) — i.e., Tokyo, European, New York, and Pacific. It is important to note, however, that they never specifically identify any news. Instead, they interpret volatility (each period's squared return) as due to news. Thus, for example, when they test for volatility in the New York market segment conditional on 'news' which occurred during the European market segment, they are actually conditioning on volatility in the European segment. They find that foreign 'news' is more important in determining today's volatility than yesterday's own news. In other words, the own lagged volatility at *t*-1 is not as important as the intervening foreign volatility. Overall, they reject the heat wave hypothesis in favor of volatility spillovers between market segments. They conclude that this result is consistent either with market dynamics which exhibit volatility persistence — possibly due to private information or heterogeneous beliefs — or with stochastic policy coordination.

Engle *et al.* also investigate the dynamic effect of country specific 'news' (volatility) on the conditional volatility in subsequent market segments. They find that Japanese 'news' had the largest impact on volatility spillovers. They suggest that this may be due to the existence of private information so that markets take time to interpret the meaning of policy action in Japan. In addition, Tokyo segment volatility was found to respond relatively little to 'news' induced shocks from other markets. The Tokyo market is quietest in terms of unconditional variance. Thus, apparently, whenever there is 'news', it has important consequences.

Baillie and Bollerslev (1990) address a number of the same questions as Engle, *et al.* (1990), except that they use spot currency prices recorded on an hourly basis for a six-month period in 1986. In addition, they examine the four major currencies — Deutsche mark, Japanese yen,

[15] See Section 3.3.5 in Chapter 3 for an overview of using likelihood ratios to test the relative explanatory power of nested models.

British pound, and Swiss franc — instead of just the yen. They use a seasonal ARCH model to explore volatility nonstationarity and fail to uncover any evidence which suggest the presence of simple or systematic volatility spillover effects between currencies or across markets. Instead, after controlling for the intra-day pattern of variance, the estimates are supportive of a heat-wave type phenomenon in the arrival of 'news' to the market (with the exception of the Deutsche mark). They find that a high (low) volatility today at hour t generally implies an increase (decrease) in the volatility at hour t the following day. This finding is contrary to Engle, *et al.* (1990), who on using less frequently sample data, found little evidence for the so called heat wave hypothesis in the yen market. Baillie and Bollerslev interpret these results as consistent with the notion of information as essentially a private phenomenon, with market participants acting on their own acquisition of new information.

In summary, time-series conditional variance techniques such as ARCH and GARCH have proven useful for examining the impact of shocks to the foreign exchange market on volatility in subsequent periods. However, although these techniques have proven useful in terms of modeling time patterns in volatility clustering, studies utilizing them have not established a link between changes in volatility and specific, identifiable news. Studies utilizing ARCH and GARCH models have established that volatility in one period (as short as an hour) may be associated with volatility in a subsequent period. If a stronger relationship between various sources of news and volatility can be verified, it may be possible to establish a link between news and volatility patterns.

2.5 Estimating Volatility With Jump Process Models

A number of authors have examined the possibility of jump processes in common stock returns.[16] Press (1967) argues that the behavior of log returns can be decomposed into *normal* and *abnormal* components. the normal component consists of the usual day-to-day price

[16] See, for example, Press (1967), Oldfield, Rogalski, and Jarrow (1977), Beckers (1981), Ball and Torous (1983) and (1985), and Jarrow and Rosenfeld (1984).

movements — e.g., due to variation in capitalization rates, a temporary imbalance between supply and demand, or the arrival of information with only marginal importance. The normal component of returns is often described by a lognormal diffusion process (i.e., Brownian motion). The abnormal component, in contrast, is due to the receipt of important new information which causes more than a marginal change in the price of the stock. However, the arrival of important information is generally assumed to be random, hence the number of news items is assumed to be distributed according to a Poisson process. In addition, the jump and diffusion components are considered to be independent. The resulting model is a combination jump-diffusion process.

Much of the empirical work using a jump-diffusion process to model common stock returns has been done with daily data. Beckers (1981) believes that using weekly or monthly data would largely obscure the underlying activity which caused a stock price change (jump). Beckers restricts the probability of a jump to be the same for a sample of 47 common stocks and estimates a jump-diffusion processes using daily returns. The probability of a jump was found to be about 12 percent, which Beckers interprets as potentially corresponding to the probability of significant new information reaching the market. Ball and Torous (1983) develop a simplified version of Becker's model by starting with a Bernoulli jump process instead of a Poisson jump process. They show that their Bernoulli process converges to the Poisson process as finer time intervals are used (e.g., moving from weekly, to daily, to intra-daily periods). Estimating the parameters in this model with maximum likelihood techniques for daily returns on 60 stocks, they find 55 demonstrated the presence of jumps. Similarly, Jarrow and Rosenfeld (1984) and Ball and Torous (1985) find evidence that daily stock returns are characterized by lognormally distributed jumps. However, these discontinuities are not apparent in monthly and weekly stock market data.

To date, only Jorion (1988) has looked at the existence of jump processes in exchange rates. The previous evidence that jumps are present in stock price returns, combined with the observed *fat tails* (leptokurtosis) in the distribution of exchange rate returns, suggests that either discontinuities may exist in the sample path of exchange rates or the assumption of stationary parameters in the diffusion process may be violated (e.g., the presence of ARCH). During fixed exchange-rate regimes, discontinuities obviously occur when parity values are realigned. But, even with flexible exchange rates, jumps in exchange rates may be generated by discontinuities in the arrival of news — which Frenkel (1981) argues should be the predominant cause of exchange rate movements — or by changes in monetary policies directed at affecting the external value of a currency.

Jorion (1988) finds that exchange rates display significant jump components, and that the jumps are more significant than those in the stock market. These discontinuities seem to arise even after explicit allowance is made for volatility clustering by incorporating an ARCH process into the model. Moreover, Jorion finds that with weekly data instead of monthly data, the jump-diffusion model is a significant improvement over the simple diffusion process model in both the foreign exchange and stock markets. The results in the stock market are in contrast with those of Jarrow and Rosenfeld (1984) who reported no significant jump process for weekly stock market returns. Jorion's analysis of subperiods of the 1974-85 sample period for both stocks and exchange rates indicate that the jump process identified for the stock market is not spread evenly over the four subperiods. The jump process for exchange rates, however, is significant for each of the four subperiods considered. Thus, the distribution of weekly exchange rate changes seems to be consistently characterized by discontinuities. Finally, Jorion compares the fit between the actual and theoretical distributions of exchange rate returns and finds that the simple diffusion and ARCH models are not quite appropriate for weekly data. The jump-diffusion process, on the other hand, does seem correctly specified.

In summary, there is considerable evidence that stock market returns are characterized by a jump-diffusion process over weekly and daily periods. In contrast, there has only been one study which establishes the presence of discontinuities in exchange rate returns — using monthly and weekly data. However, all results point toward finding even stronger evidence of a jump process for exchange rates using daily or intra-daily data. In addition, a jump process is still significant when conditional variance is incorporated into the model using an ARCH process. Thus, incorporation of a jump process may be appropriate when modeling other types of conditional variance — e.g., the release of actual news which may affect exchange rates.

2.6 The Relationship Between Volume, News, & Volatility

The relationship between asset return volatility and trading volume has recently begun receiving more attention by researchers.[17] Although the focus of this study is on the impact of macro-news on variance, studies on trading volume and volatility are briefly reviewed in this section because volume has often been used as a proxy for the arrival of news to market participants.

Admati and Pfleiderer (1988) develop a model of intraday volume and price volatility. They explicitly model *discretionary liquidity traders*. Their model implies that discretionary liquidity trading will tend to be concentrated. In addition, *informed traders* are more active in periods when liquidity trading is concentrated. It is during these periods that prices adjust to reflect new information that the informed traders possess. Thus, the major implication of their model is that volume will increase when informed traders choose to trade in the market and that volatility will also increase during these periods.

Foster and Viswanathan (1990) develop a model for common stocks which recognizes flows of information across days of the week and weekends. They find that tactics to delay trades by discretionary liquidity traders are futile, because the informed trader acts to ensure that trading costs are constant across days. With a highly informative public signal, the presence of discretionary liquidity traders yields an efficient equilibrium with two days of concentrated trading each week. With less valuable public information, Friday is the only day with concentrated trading. The implications of their model are that trading costs are highest on Monday and trading volume is low on Monday.

[17] See Admati and Pfleiderer (1988), Kim and Verrecchia (1990), and Foster and Viswanathan (1990) for papers which develop models of the impact of arrival of news to the market and volume and volatility.

Bamber (1986) examined the relationship between annual common stock earnings release surprise and trading volume around the announcement date. Bamber found that the greater the absolute value of the earnings surprise, the greater the volume around the announcement. Barclay, Litzenberger, and Warner (1990) find that when trading hours are extended trading volume increases. However, they find that variance is unaffected. Thus, they assert that variance is a function of information arrival, not the volume associated with longer trading hours.

Jain (1988) examined hourly stock returns and trading volume responses to macroeconomic announcements. Jain found that surprises in money supply and consumer price index announcements are significantly associated with stock price changes. However, trading volume was not affected by the macroeconomic surprises, which Jain interprets as evidence that market participants do not differ substantially in their interpretations of the effects of the announcements.

Stoll and Whaley (1990) examined trading/non-trading period returns for common stocks. They found that volume has permanent effects on prices and, in turn, implies that private information is revealed through trading. In other words, higher daytime volatility is not solely attributable to the greater arrival of public information, but also to the arrival of private information as revealed through trading.

2.7 Summary

The consensus from previous research in various financial asset markets is that there is clearly a relationship between changes in volatility and information. Public news announcements have been found to have a significant impact on asset volatility in the period immediately surrounding the announcement. Analysis of trading/non-trading time and hourly periods for currency markets indicates that the greatest volatility is associated with the time periods which are most likely to have a high rate of information arrival. There is also a demonstrated association between the arrival of macroeconomic news and currency volatility.

More specifically, on an *ex post* basis, currency markets have been found to react to the surprise component of various macroeconomic releases — with a greater reaction for U.S. announcements than for foreign announcements.

Time-series models such as ARCH and GARCH have proven useful for examining the impact of shocks to the foreign exchange market on volatility in subsequent periods. However, although ARCH and GARCH have proven useful for modeling the observed volatility clustering, studies using these techniques have not been able to establish a connection between volatility nonstationarity and specific, identifiable news.

There is substantial evidence that stock market returns are characterized by a jump-diffusion process over weekly and daily periods. However, only one study has established the existence of discontinuities in monthly or weekly exchange rate returns — and no study has examined daily or intra-daily data for the presence of jumps. The results so far, however, point toward finding even stronger evidence of jumps in intra-daily exchange rate data. Further, the jump process is still significant even when an ARCH process is incorporated to capture conditional variance. Therefore, incorporation of a jump process may prove fruitful when modeling conditional variance using actual news releases.

CHAPTER 3

DATA AND METHODOLOGY

Although the work of modeling news is still in its infancy, the first results by Frenkel only having appeared in 1981, the consensus is that news variables make a significant contribution to explaining exchange rate fluctuations.[1] However, many of the studies of news which have appeared in the literature have not looked at the effect of actual new releases on exchange rate returns.[2] Instead, these studies model currency returns using some form of time series process and then attribute the difference between actual returns and predicted returns to 'news.' Unfortunately, the 'news' which is asserted to move currency prices in these studies is never identified and, thus, the results are useful in only a general sense. Other studies have looked at the patterns in time-varying volatility of returns across days of the week, trading/non-trading periods, or hours of the day, in relation to the release of macroeconomic news.[3] Most of these studies, however, have not examined the impact of both U.S. and foreign macroeconomic news on currency volatility.

This study focuses on the effect of actual news announcements. Therefore, time series methods are not used since they do not address specific news items or releases. However, in the present study, trading/non-trading variance ratio tests as well as maximum-likelihood estimates of conditional-variance diffusion and jump-diffusion process models are used to measure the impact of news releases on volatility. The maximum-likelihood method is a new approach which has not been used before to test for the effect of news and is described in detail in this chapter.

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[1] Copeland (1989), pp. 315.

[2] Examples of recent studies include: Engle, Ito, and Lin (1990), Baillie and Bollerslev (1990), Joines, Kendall, and Kretzmer (1990).

[3] Examples of recent studies include: Ito and Roley (1987), Harvey and Huang (1991), Hertzel, Kendall, and Kretzmer (1990).

The organization of this chapter is as follows: The spot and futures currency data sets used are described in Section 3.1. The use of variance ratio tests over trading/non-trading periods as a method of detecting the impact of news releases is reviewed in Section 3.2. Finally, four models of the exchange rate return generating process are developed in Section 3.3 — diffusion and jump-diffusion process models with and without variance terms conditional on the release of macroeconomic information. The likelihood ratio test as a means of comparing the four models is also reviewed. The news impact of four macroeconomic variables is the focus of this study (i.e., merchandise trade balance, industrial production, consumer price index, and money supply). These variables, and the reasons for choosing them are reviewed in Section 3.4. The chapter concludes with a brief summary in Section 3.5.

3.1 Data Description

Two characteristics which differentiate the spot currency market from the markets for currency futures and options are their form of organization and location. The spot market is open virtually 24 hours a day, but — as can be seen in Figure 3.1 — trading is *handed off* sequentially from each major spot currency market to another, resulting in an almost uninterrupted 24-hour market.[4] The 24-hour spot currency market is actually a network of banks, foreign exchange brokers, and dealers operating around the globe during local business hours. Thus, the spot-market for currencies is an over-the-counter market with no central exchange or fixed trading hours. In contrast, currency futures markets are exchange-based markets with fixed trading hours. Although currency futures markets have existed at various times in other countries, most notably the London International Financial Futures Exchange (LIFFE), the largest in terms of volume is the Chicago Mercantile Exchange (CME). Currency futures trading on foreign exchanges either does not take place over the entire period studied

[4] Interestingly, the Malaysian currency market serves as a bridge between late trading in the U.S. and opening of trading in Tokyo. In effect, traders and arbitrageurs in the Malaysian market provide liquidity during the two and a half hours when currencies are not being actively traded in either the U.S. or Japan.

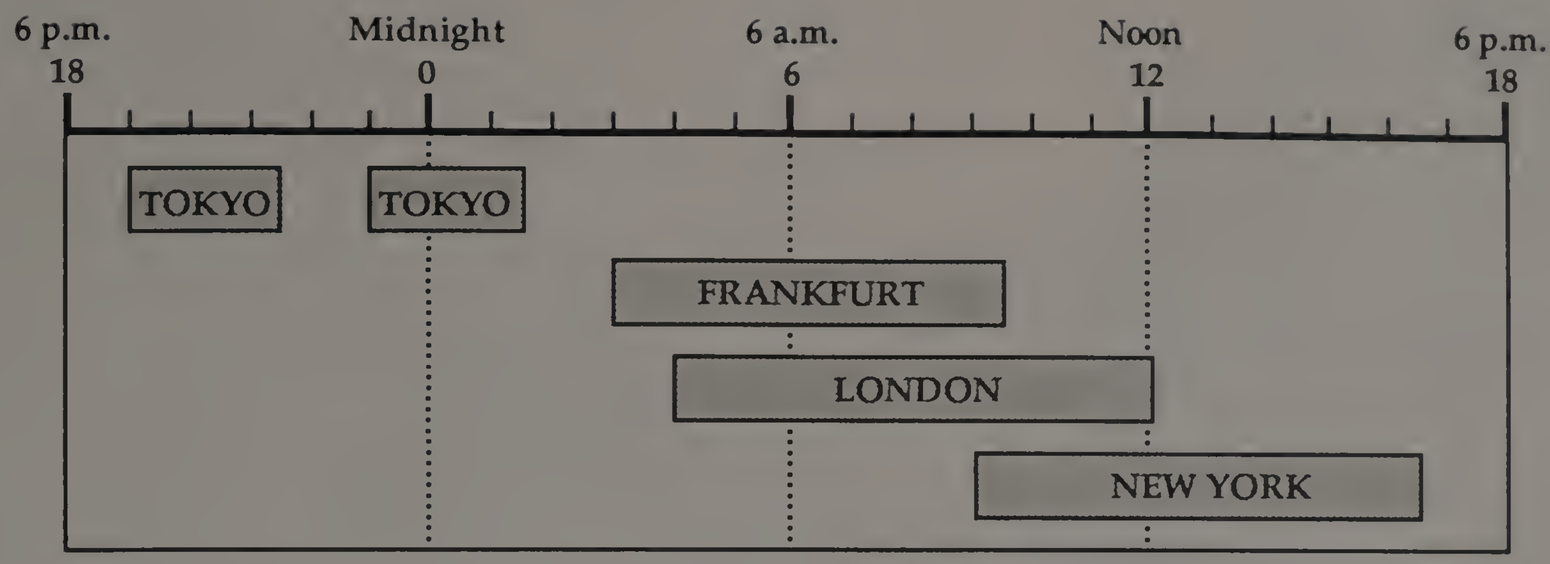

Figure 3.1: Approximate Spot Currency Trading Periods for Major World Markets

The time periods shown are approximate because, with the exception of Tokyo, the markets are not characterized by fixed trading hours. Instead, spot trading tends to "wind down" as normal business hours end. However, trading can, and does, take place before and after normal business hours, although at a lower volume. The hour-and-a-half gap in Tokyo trading is because trading stops during lunch. Times are given in terms of Eastern Standard Time (EST) — e.g., New York City.

here (1988-1990), or volume is not sufficient to allow meaningful analysis.[5]

U.S. and foreign macroeconomic news releases almost always take place during local business hours. Thus, the impact of a U.S. release is likely to occur in the period surrounding its release, and the impact of a foreign release is likely to occur in the period surrounding its release. Specifically, Harvey and Huang (1991) argue that we might observe volatility concentrated during the times when the most relevant macroeconomic news is concentrated. Consequently, for the purpose of this study, the partition of the 24-hour day is into a U.S. trading period to capture the impact of U.S. releases and a U.S. non-trading period to capture the impact of foreign releases — where foreign and domestic releases occur during each market's

[5] Harvey and Huang (1991) found that there were sufficient observations to perform a meaningful analysis on LIFFE currency futures contracts only for the 1986-87 period. In addition, they state that "the currency futures contracts on the LIFFE never generated much interest and trading was finally suspended in 1990."

respective business hours.[6] The trading and non-trading periods used in this study for spot and futures currency markets are shown in Figure 3.2.

The analysis in this study is based on daily data over the three-year period from January, 1988 through December, 1990. The data consists of foreign exchange quotes and prices from the spot and futures markets for the British pound (BP), Deutsche mark (DM), and Japanese yen (JY). The U.S. dollar is used as the *numeraire* for all three currencies — which simply means that all foreign exchange rates are expressed as the number of units of the foreign currency which can be purchased with one dollar. Spot currency quotes were obtained from Data Resources Incorporated (DRI) and Bankers Trust Co. (the latter as reported in the Wall Street Journal). Open and close prices for currency futures were obtained from the Chicago Mercantile Exchange.

Spot quotes were obtained from the French, British, and U.S. currency markets. As can be seen in Panel A of Figure 3.2, the 2 p.m. Paris (8 a.m. NY) quote is used as a proxy for the 9 a.m. open in New York.[7] This results in a trading period which begins one hour earlier than the actual trading period. However, since the focus of this study is on capturing the effects of information releases (which occur primarily between 9 a.m. and 11 a.m. in the U.S.) the earlier "open" will not affect the results. Similarly, the 5 p.m. London close is used as a proxy for the 12-noon New York quote. Both the London and Paris quotes were obtained from DRI. Finally, the Bankers Trust Co. 3 p.m. New York quote is used as the "close" quote, even though trading

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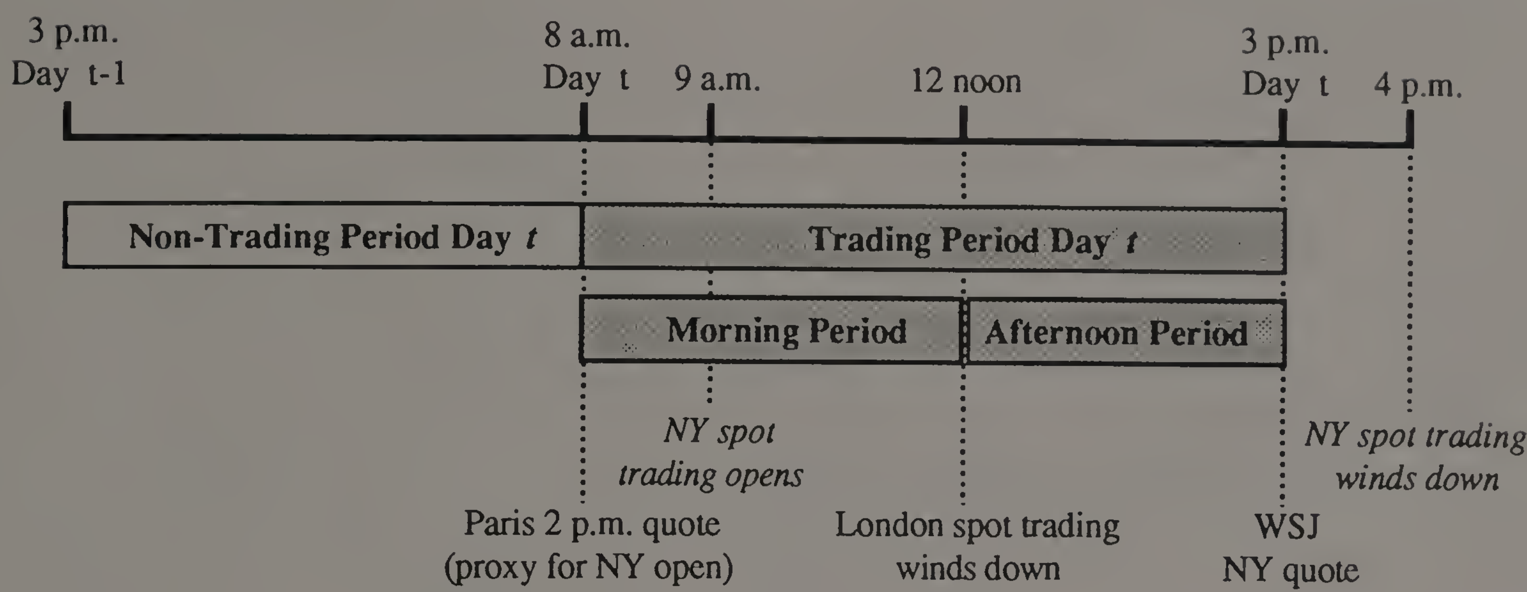
[6] As can be seen in Figure 3.1, the London trading period overlaps the New York trading period by three hours. However, since U.K. macroeconomic releases are made in the morning, at the beginning of the U.K. trading period, the U.S. non-trading partition adopted in this study will still contain the U.K. releases and allow tests for the impact on the volatility in that period. Further, open and close data for the U.K. and Japanese futures markets could be used to compute foreign trading period returns for each country rather than relying on the fact that their trading period is contained in the U.S. non-trading period. However, currency futures contracts stopped trading on the LIFFE in 1990, did not trade on an organized exchange in Japan during the period of this study, and have never been traded in Germany.

[7] This "adjusted" trading period seems justified. For Example, Ito and Roley (1987) had 9:00 a.m. NY open quotes, but chose to use returns from Tokyo close to NY 12-noon to capture the effect of U.S. industrial production and producer price index releases, which are released at either 8:30 or 9:00 a.m. during their sample period. In addition, the high level of liquidity in the foreign exchange market allows use of a locational arbitrage argument to state that spot exchange rates in London and New York will in fact be equal. The high liquidity and low transactions costs mean that if the exchange rates in two markets were not equal at a given time, arbitrageurs could simultaneously buy currency in one market and sell it in the other market to make a risk-free arbitrage profit. Thus, arbitrage opportunities quickly disappear and the prices in the two markets become equal again.

Panel A: Spot Currency Market



Panel B: Currency Futures Market

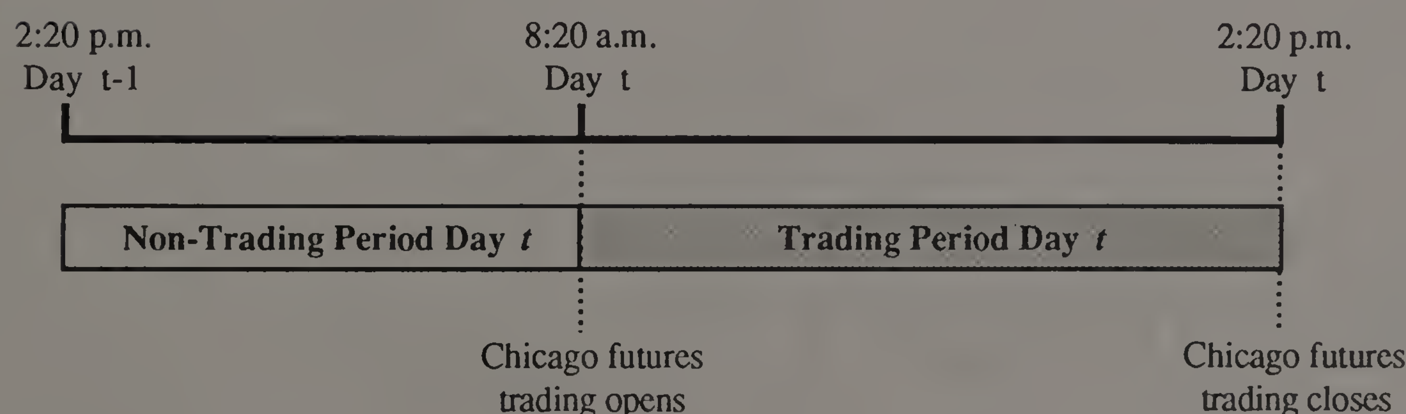


Figure 3.2: Trading and Non-Trading Periods Used in this Study

The actual trading period for the cash market differs from the trading period used for this study because quotes were unavailable for exact New York open and close times. Instead, quotes for an hour earlier were used as close proxies for the true open and close (i.e., 2 p.m. Paris and 3 p.m. New York respectively). This also has the advantage of making the trading periods for the spot and futures markets nearly contemporaneous. All times are given in terms of Eastern Standard Time (e.g., New York City).

volume doesn't taper off until the end of regular business hours at 4 p.m. The choice of this quote as the closing price was simply due to the availability of the data in *The Wall Street Journal*.

Futures open and close prices were obtained directly from the CME. As is shown in Panel B of Figure 3.2, the 8:20 a.m. opening and 2:20 p.m. closing prices provide a trading period nearly the same as that used in this study for the spot market.[8] Currency futures prices used were for the nearest to delivery contract, rolled over into the next position contract at the beginning of the delivery month.

Intra-day returns[9] for trading, non-trading, and morning and afternoon trading sub-periods, as shown in Figure 3.2, are calculated for spot exchange rates and futures contracts as follows:[10]

$$x_t(T) = \ln(P_{C,t} / P_{O,t})*100 \tag{3.1}$$

$$x_t(NT) = \ln(P_{O,t} / P_{C,t-1})*100 \tag{3.2}$$

$$x_t(a.m.) = \ln(P_{N,t} / P_{O,t})*100 \tag{3.3}$$

$$x_t(p.m.) = \ln(P_{C,t} / P_{N,t})*100 \tag{3.4}$$

where: $x_t(T)$ = continuously compounded return over the trading period for day t (or non-trading period (NT), morning trading period (a.m.), afternoon trading period (p.m.));

$P_{O,t}$ = opening futures price or spot exchange rate at the beginning of the U.S. trading period on day t;

$P_{C,t}$ = closing futures price or spot exchange rate at the end of the U.S. trading period on day t;

$P_{N,t}$ = 12-noon spot exchange rate from the U.S. trading period on day t.

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[8] Trading of all CME currency futures contracts takes place between approximately 8:20 a.m. and 2:30 p.m. (EST). However, the closing times of the contracts are staggered such that the DM closes at 2:20 p.m., the JY closes at 2:22 p.m., and the BP closes at 2:24 p.m. The difference in closing times is small enough that all three are treated as if they had a common closing time of 2:20 p.m.

[9] See Appendix A for an examination of the distributional characteristics of currency futures trading and non-trading period returns for the three currencies studied. Normality is rejected for all but DM trading period and JY non-trading period returns.

[10] In this study what is actually being measured are the percentage changes in exchange rates and currency futures prices, not the "return" on an investment. The distinction is due to the fact that there is not common agreement as to how the "return" on a futures contract should be measured. For example, should the "investment" at the beginning of the period be the amount deposited in a margin account, or should zero initial investment be assumed? For an "investment" in a currency, the funds would presumably be invested in an interest bearing account or bonds. Thus, a true spot "return" would also include interest income. However, in this study, the term "return" is used in the sense of the percentage change in either the spot exchange rate or the futures contract price.

3.2 Variance Ratio Tests of Time Varying Volatility

Following French and Roll (1986) and Harvey and Huang (1991) hourly variance rates are calculated for trading and non-trading period returns according to (3.5) and variance-rate ratios according to (3.6).

$$V_h = \frac{1}{T*H}\sum_{t=1}^{T}\left(x_t - E[x_t]\right)^2 \tag{3.5}$$

$$\text{Variance Rate Ratio} = \frac{V_h(N)}{V_h(D)} \sim F(n,d) \tag{3.6}$$

where:

where:	x_t	=	the log return at time t for the series of interest (e.g., trading or non-trading) as defined in (3.1) through (3.4);
	H	=	the number of hours in the trading or non-trading period of interest;
	T	=	the number of observations (periods);
	$V_h(N)$	=	numerator hourly variance rate (e.g., for the set of returns with the larger variance);
	$V_h(D)$	=	denominator hourly variance rate (e.g., for the set of returns with the smaller variance);
	$F(n,d)$	=	an F-distribution with numerator and denominator degrees of freedom equal to n and d (n = numerator observations minus one, and d = denominator observations minus one). The F-statistic allows a test of the hypothesis that the numerator variance is significantly larger than the denominator variance.

The need to adjust for the number of hours in each period is illustrated in Figure 3.3 for the spot currency market. As can be seen, the weekend non-trading period is nearly four times longer than the weekday non-trading periods, which are in turn almost two-and-a-half times longer than the trading periods. If information arrives at a uniform rate, then — when the market is open — the variance over a two-hour period should be twice a large as the variance over a one-hour period.[11] Thus, since foreign exchange trading takes place twenty-four-hours a day, the variances of both trading and non-trading period variances need to be scaled by the number of hours in each period to obtain hourly variance rates which are comparable. Of course, information does not arrive at a uniform rate. But, if variances are expressed on an hourly basis, then any variance-rate differences will be due to either differences in the clustering of

[11] See French and Roll (1986), Oldfield and Rogalski (1980), Stoll and Whaley (1990).

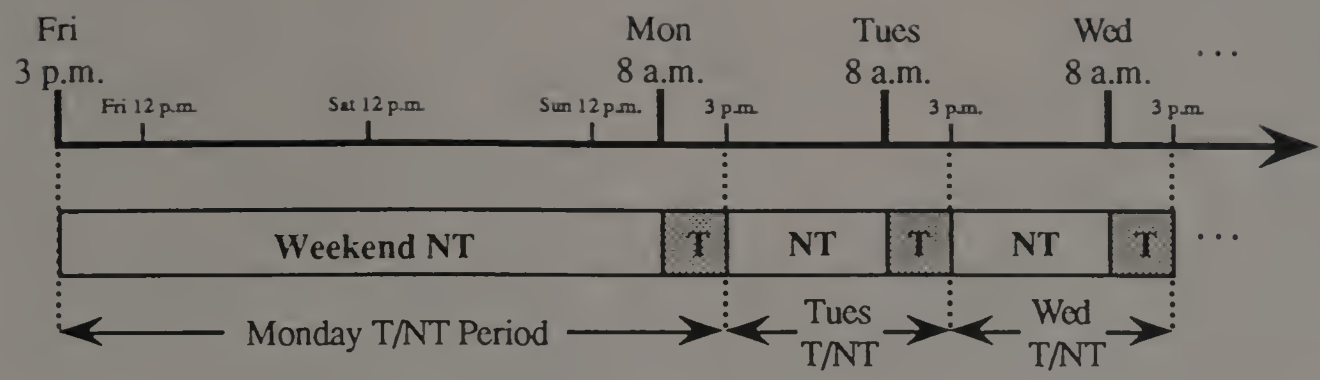

Figure 3.3: Daily Spot Market Trading/Non-Trading Periods

All times are given in terms of Eastern Standard Time, not the local time for each market. Abbreviations: NT = U.S. non-trading period, T = U.S. trading period. The abbreviation T/NT is used to denote the trading/non-trading period for a particular day as defined in this study. For example, although the Tuesday NT period is from Monday at 3 p.m. till Tuesday at 8 a.m., when the Japanese trading period occurred during this time, it was Tuesday in Japan.

information releases, or due to differences in the relative impact of information releases. The actual number of hours in the spot and futures trading periods used in this study are shown below in Table 3.1.

Use of the variance-rate ratio (3.6) to test for volatility differences between trading and non-trading periods assumes that returns are serially uncorrelated.[12] Correlations for trading and non-trading period currency returns are presented in Appendix A — which shows that the autocorrelations for the BP, DM, and JY are generally considerably less than 0.10.[13] The lack of

Table 3.1

Hours Per Trading/Non-Trading Period

	Hours Per Period	
	Spot	Futures
Weekend non-trading period	65	66
Weeknight non-trading period	17	18
Weekday trading period	7	6

[12] Harvey and Huang (1991).

[13] These results are consistent with Joines, Kendall, and Kretzmer (1990) who test for autocorrelations in intra-day currency futures returns and conclude that the returns are independent.

high serial autocorrelation allows the calculation of variance rates across non-sequential subsets of the sample of returns without invalidating the variance-rate ratio test statistic.[14]

As an example of the variance ratio test, suppose the variance-rate estimates for a currency — conditional on U.S. macroeconomic release for trading-period returns and conditional on foreign macroeconomic release for non-trading period returns are:
V_h(Trading: U.S. info) = 0.080, and V_h(Non-Trading: Foreign info) = 0.020. Since the trading-period variance is larger, the variance-rate ratio is 0.080/0.020 = 4.00. If there are 21 trading-period observations and 15 non-trading period observations, the F-distribution critical value at the 1% level is $F(20, 14) = 3.51$. Thus, in this example, the null-hypothesis that the variances are equal would be rejected at the 1% level — providing evidence that U.S. macroeconomic releases have a greater impact on currency variance than the corresponding foreign releases.

3.3 Likelihood Ratio Tests of Time Varying Volatility

Although a substantial body of work has been published on the volatility of exchange rates, Copeland (1989) states that "no combination of 'news' variables has yet to come any where near explaining this volatility." Still, Copeland believes that 'news' variables explain somewhere between 5% and 20% of monthly variation in the major currencies over the decade of the 1980s. Variance ratio techniques — like those described in Section 3.2 — are useful in that they allow some conclusions to be drawn about the relative magnitude of impacts for information releases which occur during trading periods versus those which occur during non-trading periods. However, trading/non-trading (T/NT) variance ratios allow little to be said about what proportion of the variance on macroeconomic release dates can be attributed to the release of new information, and what proportion is due to the usual day-to-day functioning of the currency market (as well as other non-macroeconomic news and events not included in a particular study). Two of the four models developed in this section are designed to help answer

[14] For example, variance rates for trading or non-trading period returns on days of macroeconomic releases can be computed, even though there may be several days or more between observations.

this question — by introducing conditional variance terms into diffusion and jump-diffusion process models of exchange rate returns.

This section is organized as follows: In Sections 3.3.1 through 3.3.4, four models (I through IV) are developed. Model I is a simple diffusion process, while Model II is a diffusion process with a variance term conditional on macroeconomic releases. Similarly, Model III is a jump-diffusion process, while Model IV is a jump-diffusion process with a conditional variance term. The likelihood-ratio test as a means of comparing the ability of the various models to explain the exchange rate return generating process is explained in Section 3.3.5.

3.3.1 *A Simple Diffusion Process — Model I*

A time series is said to follow a pure random walk if the price (P_t) change from one period to the next is purely random, that is, if $P_t = P_{t-1} + z_t$ — where z_t is completely random. The pure random walk can also be expressed in terms of continuous-time returns as $dP_t/P_t = z_t$. A time series follows a random walk with drift if the change in price from one period to the next is equal to a drift factor, α, plus a purely random component, that is, if $dP_t/P_t = \alpha dt + \sigma dz_t$. This formulation of a random walk is also called a diffusion process and is one of the simplest (and most common) stochastic models of a price-return process. In discrete time a diffusion process for spot or futures currency returns is:

$$x_t = \mu + \sigma_1 z, \tag{3.7}$$

where:
- x_t = trading or non-trading period (which ever is of interest) log return for day t as defined in equations (3.1) and (3.2);
- μ = expected return;
- σ_1^2 = unconditional variance of the return (i.e., not conditional on the release of any macroeconomic information);
- z = a standard Wiener process (e.g., completely random, displaying no pattern over time).

The assumption that price returns follow this simple diffusion process implies that $x_t \sim N(\mu, \sigma_1^2)$ and that the probability density function (p.d.f.) is that of a normal distribution:

$$f(x;\mu,\sigma_1^2) = \frac{1}{\sqrt{2\pi\sigma_1^2}} \exp\left[-\frac{(x-\mu)^2}{2\sigma_1^2}\right]. \tag{3.8}$$

Thus, the μ and σ_1^2 parameters in equation (3.7) can be estimated by maximizing the log-likelihood function for the model.[15] The log-likelihood function, $\ln L = \ln L(\gamma; x)$, is identical to the joint p.d.f. of the sample, but is interpreted as a function of the unknown parameter vector, $\gamma = \{\mu, \sigma_1^2\}$, given the observed returns — instead of as a function of the values of the random variable (returns), which are assumed to be known. Using the fact that the log returns are assumed to be normally distributed, and the definition of the log-likelihood function,

$$\ln L = \ln\left\{\prod_{t=1}^{T} f(x_t; \gamma)\right\}, \tag{3.9}$$

the log-likelihood function (ln$L$) for the simple diffusion process in equation (3.7) can be written as:

$$\ln L = \ln\left\{\prod_{t=1}^{T} \frac{1}{\sqrt{2\pi\sigma_1^2}} \exp\left[-\frac{1}{2}\frac{(x_t - \mu)^2}{\sigma_1^2}\right]\right\}, \tag{3.10}$$

which simplifies to:

$$\ln L = -\frac{T}{2}\ln(2\pi) - \frac{T}{2}\ln(\sigma_1^2) - \frac{1}{2}\sum_{t=1}^{T}\frac{(x_t - \mu)^2}{\sigma_1^2}, \tag{3.11}$$

where T is the number of returns (observations) in the sample.

The first order conditions for maximum likelihood parameter estimates are obtained by partially differentiating (3.11) with respect to μ and σ_1^2 as follows:

$$\frac{\partial \ln L(x; \mu, \sigma_1^2)}{\partial \mu} \tag{3.12}$$

$$\frac{\partial \ln L(x; \mu, \sigma_1^2)}{\partial \sigma_1^2} \tag{3.13}$$

and setting each partial derivative equal to zero. Simultaneously solving the resulting system of equations across all observations in the sample can be accomplished through the use of gradient methods — e.g., some variation of the Gauss-Newton optimization technique.[16] Many

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[15] See Judge *et al.* (1988), pp. 62-68, for an introduction to likelihood functions.

[16] Model I has well known closed-form solutions for estimates of the parameters $\mu = 1/T\ \Sigma_i\ x_i$ and

standard econometric computer packages, however, contain numerical maximum likelihood estimation (MLE) routines which can be used to obtain maximum-likelihood estimates of the parameters (μ, σ_1^2) in equation (3.7). Appendix B contains a complete explanation of how estimation of the parameters in the four models presented in this chapter can be operationalized using standard computer packages such as TSP, as well as detailed derivations of the log-likelihood functions.

3.3.2 *A Diffusion Process With Conditional Variance — Model II*

Trading/non-trading period variance ratio results from this study as well as results from previous studies indicate that the variance of currency returns differ between days of no information release and days on which information releases do occur.[17] This suggests that a diffusion process model with an additional variance term, conditional on information release, may describe the currency return generating process better than a simple diffusion process. Thus, a conditional variance term — which allows an increase or decrease in variance for periods with information releases compared to periods with no information release — can be added to the simple diffusion process (3.7) :

$$x_t = \mu + \sigma_1 z_1 + \Phi \sigma_2 z_2, \tag{3.14}$$

where:
- Φ = a bivariate (0, 1) dummy variable which takes on the value one if macroeconomic information is released that period (e.g., U.S. information if trading-period returns are being analyzed, and foreign information for the currency being studied if non-trading period returns are being analyzed), and zero otherwise;
- σ_1^2 = the overall variance for all return periods in the sample (both with and without information releases);
- σ_2^2 = the increase or decrease in variance for return periods in which information was released;

and other variables are as previously defined for (3.7).

By modeling the possibility of differing variances for information or non-information periods as in (3.14), Model I (3.7) is *nested* in Model II and can be tested against it using a likelihood-ratio

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$\sigma^2 = 1/T\ \Sigma_i(x_i - E[x])^2$. However, the models developed in the following sections (Models II, III, IV) have more than two parameters and, therefore, estimates must be obtained by maximizing the log-likelihood function using an iterative numerical optimization technique.

[17] See Ito and Roley (1987), Harvey and Huang (1991), Hertzel, Kendall, and Kretzmer (1990), Joines, Kendall, and Kretzmer (1990).

test for nested hypotheses (a test which is explained in more detail in Section 3.3.5). The p.d.f. for (3.14) is a modified version of the normal density — where the term $(\sigma_1^2 + \Phi\sigma_2^2)$ is substituted throughout for σ_1^2 to obtain:

$$f\left(x;\mu,(\sigma_1^2 + \Phi\sigma_2^2)\right) = \frac{1}{\sqrt{2\pi(\sigma_1^2 + \Phi\sigma_2^2)}} \exp\left[-\frac{(x-\mu)^2}{2(\sigma_1^2 + \Phi\sigma_2^2)}\right]. \qquad (3.15)$$

The log-likelihood function for (3.14) is derived in exactly the same manner as the one for (3.7), except that the term $(\sigma_1^2 + \Phi\sigma_2^2)$ is substituted throughout for σ_1^2, to obtain:

$$\ln L = -\frac{T}{2}\ln(2\pi) - \frac{T}{2}\ln\left(\sigma_1^2 + \Phi\sigma_2^2\right) - \frac{1}{2}\sum_{t=1}^{T}\frac{(x_t-\mu)^2}{\left(\sigma_1^2 + \Phi\sigma_2^2\right)}. \qquad (3.16)$$

The parameter vector, $\gamma = \{\mu, \sigma_1^2, \sigma_2^2\}$, for this conditional-diffusion model can be estimated by maximizing (3.16) across all observations as was described for the simple diffusion process in Section 3.3.1.

3.3.3 *A Mixed Jump-Diffusion Process — Model III*

Jorion (1988) models a mixed jump-diffusion process[18], $dP_t/P_t = \alpha dt + \sigma dz_t + dq_t$, in which the Poisson process dq_t is characterized by a mean number of jumps (λ) occurring per unit time as well as jump size Y. In discrete time the process is given by:

$$x_t = \mu + \sigma_1 z_1 + \sum_{j=1}^{J}\ln Y_t\ , \qquad (3.17)$$

where:
- x_t = trading or non-trading period log return for day t;
- μ = expected return;
- σ_1^2 = unconditional variance of the return;
- z = a standard Wiener process;
- Y = the jump size, a Poisson process, which is assumed to be distributed lognormally independently of z, $\ln Y \sim N(\theta,\delta^2)$, and where J is the actual number of jumps during the time interval. Results by Ball and Torous (1985) indicate that in practice truncation at J = 10 provides satisfactory accuracy for this model;
- λ = the jump intensity — mean number of jumps occurring per unit of time (e.g., trading or non-trading period);
- θ = the mean jump size;
- δ^2 = the variance of the jump size.

[18] Jorion's jump-diffusion process model builds on earlier work by Ball and Torous (1983) and (1985).

Since the jump process is assumed to be a Poisson process independent of the Wiener process, the p.d.f. function for the mixed jump-diffusion process with J jumps per period can be written as the product of Poisson and normal p.d.f.s:

$$f(x)=\sum_{j=0}^{J}\frac{e^{-\lambda}\lambda^{j}}{j!}\frac{1}{\sqrt{2\pi(\sigma_1^2+\delta^2 j)}}\exp\left[-\frac{1}{2}\frac{(x_t-\mu-\theta j)^2}{(\sigma_1^2+\delta^2 j)}\right], \tag{3.18}$$

where

$$f(x;\lambda)=\frac{e^{-\lambda}\lambda^{j}}{j!} \tag{3.19}$$

is the Poisson p.d.f. for the probability of j jumps occurring in period t, and

$$f\left(x;(\mu-\theta),(\sigma_1^2+\delta^2 j)\right)=\frac{1}{\sqrt{2\pi(\sigma_1^2+\delta^2 j)}}\exp\left[-\frac{1}{2}\frac{(x_t-\mu-\theta j)^2}{(\sigma_1^2+\delta^2 j)}\right] \tag{3.20}$$

is the normal density for a mixed jump-diffusion process. Taking the log of the products of the joint p.d.f.s, the log-likelihood function can be written as:

$$\begin{aligned}\ln L &= \ln\left\{\prod_{t=1}^{T}\sum_{j=0}^{J} f(x;\lambda)\cdot f(x;\mu,\sigma_1^2,\theta,\delta^2)\right\}\\ &= \ln\left\{\prod_{t=1}^{T}\sum_{j=0}^{J}\left(e^{-\lambda}\right)\frac{\lambda^{j}}{j!}\frac{1}{\sqrt{2\pi(\sigma_1^2+\delta^2 j)}}\exp\left[-\frac{(x_t-\mu-\theta j)^2}{2(\sigma_1^2+\delta^2 j)}\right]\right\},\end{aligned} \tag{3.21}$$

which simplifies to:

$$\ln L = -T\lambda-\frac{T}{2}\ln(2\pi)+\ln\sum_{t=1}^{T}\sum_{j=0}^{J}\frac{\lambda^{j}}{j!}\frac{1}{\sqrt{(\sigma_1^2+\delta^2 j)}}\exp\left[-\frac{(x_t-\mu-\theta j)^2}{2(\sigma_1^2+\delta^2 j)}\right]. \tag{3.22}$$

Maximizing (3.22) across all observations in the sample will yield estimates of the parameter vector $\gamma=\{\mu,\sigma_1^2,\lambda,\theta,\delta^2\}$.

3.3.4 *A Conditional-Variance/Jump-Diffusion Process — Model IV*

Just as the simple diffusion process of Model I was made more general by incorporating a conditional variance term in Model II, Jorion's jump-diffusion process in model III can be made more general by also incorporating a conditional variance term. Model IV includes the conditional variance term, as shown below.

$$x_t = \mu + \sigma_1 z_1 + \Phi\sigma_2 z_2 + \sum_{j=1}^{J} \ln Y_t \tag{3.23}$$

where: Φ = a bivariate (0, 1) dummy variable which takes on the value one if macroeconomic information is released that period (e.g., U.S. information if trading-period returns are being analyzed, and foreign information for the currency being studied if non-trading period returns are being analyzed), and zero otherwise;

σ_1^2 = the overall variance for all return periods in the sample (both with and without information releases);

σ_2^2 = the increase or decrease in variance for return periods in which information was released;

and other variables are as previously defined for (3.17).

By modeling the exchange-rate return-generating process as in Model IV (3.23), Model III (3.17) and Model I (3.7) are nested in it and can be tested relative to each other with likelihood ratio tests.

Just as the p.d.f. for Model I in Section 3.3.2 is a modified version of the normal density, the p.d.f. for (3.23) is simply a modified version of (3.18) — where the term $(\sigma_1^2 + \Phi\sigma_2^2)$ is substituted throughout for σ_1^2 to obtain:

$$f(x) = \sum_{j=0}^{J} \frac{e^{-\lambda}\lambda^j}{j!} \frac{1}{\sqrt{2\pi(\sigma_1^2 + \Phi\sigma_2^2 + \delta^2 j)}} \exp\left[-\frac{1}{2} \frac{(x_t - \mu - \theta j)^2}{(\sigma_1^2 + \Phi\sigma_2^2 + \delta^2 j)} \right]. \tag{3.24}$$

The log-likelihood function for (3.23) is derived in exactly the same manner as the one for (3.17), except that the term $(\sigma_1^2 + \Phi\sigma_2^2)$ is substituted throughout for σ_1^2 to obtain:

$$\begin{aligned} \ln L = & -T\lambda - \frac{T}{2}\ln(2\pi) \\ & + \ln \sum_{t=1}^{T} \sum_{j=0}^{J} \frac{\lambda^j}{j!} \frac{1}{\sqrt{(\sigma_1^2 + \Phi\sigma_2^2 + \delta^2 j)}} \exp\left[-\frac{(x_t - \mu - \theta j)^2}{2(\sigma_1^2 + \Phi\sigma_2^2 + \delta^2 j)} \right] \end{aligned} \tag{3.25}$$

The parameter vector $\gamma = \{\mu, \sigma_1^2, \sigma_2^2, \lambda, \theta, \delta^2\}$ for this conditional-variance/jump-diffusion process can be estimated by maximizing (3.25) across all observations as was described for the simple diffusion process of Model I in Section 3.3.1.

3.3.5 *Evaluating the Models with Log-Likelihood Hypothesis Tests*

Maximum likelihood estimation of the parameters in each of the four models presented in the previous sections results in a log-likelihood value for each model. These log-likelihood values allow formal tests of the relative ability of the various models to explain the exchange rate return generating process. A version of the generalized likelihood ratio, $\Lambda = L(\gamma_0 ; x) / L(\gamma_A ; x)$, can be used because $-2*\ln(\Lambda)$ is asymptotically distributed Chi-square — plus the fact that what is being maximized is the log of the likelihood function.[19] Thus, the test statistic for the null hypotheses versus the alternative hypotheses is:

$$\begin{aligned} -2*\ln(\Lambda) &= -2*\ln\left[\frac{L(\gamma_0;x)}{L(\gamma_A;x)}\right] \\ &= -2\left[\ln L(\gamma_0;x) - \ln L(\gamma_A;x)\right], \end{aligned} \tag{3.26}$$

where:

	$-2*\ln(\Lambda)$	~	χ^2_η (i.e., distributed Chi-square with η degrees of freedom);
	η	=	the number of additional parameters in the alternate hypothesis model compared to the number of parameters in the null hypothesis model (or, alternately, the number of parameters restricted to equal zero in the null hypothesis);
	γ_0	=	the null-hypothesis model parameter vector (e.g., the model with the parameter set which is nested in the alternate parameter set);
	γ_A	=	the alternate-hypothesis model parameter vector (e.g., the larger parameter set);

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19 Log-likelihood values are always negative. The intuition behind the negative value is that the probability of obtaining any observation, x_t, is the p.d.f. $f(x_t;\gamma)$ — which can only take on values between zero and one. The likelihood value from maximizing this function across all observations would be the joint probability (i.e., product) of obtaining that particular set of observations, a very small number. However, since (for simplicity) the log of the likelihood function is being maximized, the likelihood value will be the sum of the logs of the individual probabilities. Since the natural log of a number between zero and one is negative, the log-likelihood will be the sum of a series of negative values — resulting in a negative log-likelihood value. Further, the larger a likelihood value, the greater the probability that the model of interest came from that data set. Therefore, the larger the log-likelihood value (closer to zero) the greater the probability that the model actually describes that set of data.

As an example of the likelihood-ratio test, suppose the log-likelihood values from ML estimation of the parameters in Model I and II are $\ln L(\gamma_0;x) = -500$ and $\ln L(\gamma_A;x) = -475$, respectively. Since the parameter vector for Model I is nested in that of Model II, Model I is the null-hypothesis model — i.e., $\gamma_0 = \{\mu, \sigma_1^2\}$ and $\gamma_A = \{\mu, \sigma_1^2, \sigma_2^2\}$. The Chi-square test statistic is $-2[-500 - (-475)] = 50$, which is compared to a 1% critical value of $\chi^2_{\eta=1} = 6.63$, where $\eta = (3 - 2)$ degrees of freedom. Thus, at the 1% significance level, Model I would be rejected in favor of Model II. The other models presented in the previous sections are tested against Model I and versus each other in a similar manner.

When faced with the problem of choosing between models with non-nested parameter vectors — e.g., Models II ($\gamma = \{\mu, \sigma_1^2, \lambda, \theta, \delta^2\}$) and III ($\gamma = \{\mu, \sigma_1^2, \sigma_2^2\}$) — a nested likelihood ratio test is not possible and use of the maximum likelihood to rank the models invariably leads to choosing the model with the larger number of parameters. Comparison of models where the parameter vector of one is not nested in the other can, however, be accomplished by ranking the models using the Schwarz Criterion (SC), which adjusts the log-likelihood value by the number of parameters in the model according to the equation:[20]

$$SC = \ln L(\gamma;x) - .5 \times k \times \ln(T), \tag{3.27}$$

where: k = the number of parameters in the model;
T = the number of observations in the sample;
$\ln L(\gamma;x)$ = the log-likelihood value for the model the Schwarz criterion is being calculated for.

The closer a model's SC is to zero, the better it is in terms of the Schwarz Criterion.[21] Thus, models with more parameters are penalized in terms of the SC. A problem with the Schwarz Criterion, however, is that it does not allow a formal hypothesis test of one model versus another. Still, it allows *non-nested* models to be ranked without an automatic bias in favor of those containing a greater number of explanatory variables.

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[20] Schwarz (1978)

[21] Log-likelihood values are always negative, resulting in a negative SC value as well. Thus, the larger a model's SC (e.g., closer to zero) the better the model in terms of the Schwarz Criterion.

3.4 Macroeconomic News Releases

Information which potentially affects trading and pricing of financial assets is generally believed to be produced continuously. Macroeconomic news, however, is often generated in a discrete fashion and released at regularly scheduled intervals. For currencies, such information series include: merchandise trade balance (MTB), industrial production (IP), consumer price index (CPI), and money supply (MS). In this study, the impact of these four U.S. macroeconomic releases on trading period volatility in the currency spot, futures, and options markets is examined. Equivalent macroeconomic releases for Japan, Britain, and Germany are used to examine the impact of foreign releases on non-trading period currency volatility. A description of each of the U.S. macroeconomic information releases as well as sources of U.S. and foreign release dates are presented in Table 3.2.

The four macroeconomic variables listed above were chosen to represent news in this study, in part, because they have often been shown to affect asset prices and exchange rates in previous studies. A summary of the results from previous studies on the relationship between financial asset prices and these and other macroeconomic variables is given in Table 3.3. A second factor behind the choice of these macroeconomic variables to represent news is that equivalent foreign macroeconomic variables are available for the countries corresponding to the three currencies studied here. Although there are approximately 20 U.S. macroeconomic variables which are commonly followed by economists and analysts, the number of variables followed for major developed nations is much smaller. The foreign versions[22] of the four macroeconomic variables used in this study are commonly followed in this country — e.g., their tentative/scheduled release dates are reported in publications of large brokerage houses such as Merrill Lynch, S.G. Warburg, and Goldman Sachs — which indicates that they may be likely to have an impact on exchange rates and other asset prices. Thus, in this study, macroeconomic news is restricted to

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[22] For a discussion of the relative quality of economic releases of industrialized countries see "The Good Statistics Guide," *The Economist*, September 7, 1991, pp. 88 which offers a survey of the quality of country macroeconomic releases. For example, statisticians ranked the countries in this study as follows: Germany (6), U.S. (7), Japan (8), and Britain (9). In fact, Canada, Australia, Sweden, Holland, and France were all ranked ahead of the countries in this study in terms of the overall usefullness of their macroeconomic releases.

the same four variables for the U.S. and the three foreign countries (Britain, Germany, and Japan). In the following sub-sections, the economic intuition as to why each of the four macroeconomic variables might affect exchange rates are briefly reviewed.

3.4.1 *Models of Exchange Rate Movements*

Three of the most common models of exchange rate movements are: interest rate parity (IRP), purchasing power parity (PPP), and the monetary balance of payments (MBP) model. Participants in the currency markets are likely to use some combination of these three models at any point in time to assess the potential for changes in exchange rates. Goodhart (1992), for example, believes that the reaction of exchange rates to news is an under-reaction, rather than an over-reaction. Goodhart also believes that foreign exchange prices are set by a combination of commercial orders, random walk operators, and fundamentalists (participants who attempt to forecast exchange rate movements based a combination of one or more of these three models). Goodhart also believes that survey data[23] is dominated by fundamentalists — and interprets this as evidence that a substantial proportion of market participants are fundamentalists and that variables in these models (IRP, PPP, and MBP) should be important to market participants. *Thumbnail sketches* of these three common models of exchange rates are given below.[24]

> *Interest Rate Parity*: According to this model, changes in the exchange rate (XR) between two countries are approximately equal to the difference in the respective interest rates for the two countries: $\Delta XR \approx i_h - i_f$, where, i_h is the home country interest rate and i_f is the foreign country interest rate.
>
> *Purchasing Power Parity*: According to this model, changes in the exchange rate between two countries are approximately equal to the difference in the respective inflation rates for the two countries: $\Delta XR \approx I_h - I_f$, where, I_h is the home country inflation rate and I_f is the foreign country inflation rate.

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23 Survey data is provided to market participants by, for example, Money Market Services and Technical Data Incorporated and consists of the mean, median, and (in the case of Technical Data) standard deviation of analysts' forecasts. The mean and median are generally interpreted as a *concensus* forecast.

24 For a more detailed explanation, the reader should read any international finance textbook, or Copeland (1989) Chapters 2, 3, and 5, for a good presentation of these models of exchange rate determination.

Table 3.2

U.S. Macroeconomic Information Releases
Used in this Study

Information Series	Release Source	Release Time
Merchandise Trade Balance	Bureau of the Census	8:30 a.m. EST; Monthly
Industrial Production	Bureau of Labor and Statistics	9-9:15 a.m. EST; Monthly
Money Supply	Federal Reserve	4:10 p.m. EST; Weekly
Consumer Price Index	Bureau of Labor and Statistics	8:30 a.m. EST; Monthly

Notes:
1. Money supply releases normally take place on Thursdays, while the release day of the week for the other three U.S. macroinformation releases can vary from month to month.
2. Similar releases of macroinformation in the United Kingdom and Japan are not necessarily made at the same time of day as those of the U.S. releases.
3. U.K. releases are on a monthly basis.
4. Japanese releases are not made on a predetermined schedule. However, most releases take place once a month.

Sources of U.S. and Foreign Macroeconomic
Information Release Dates Used in This Study

Phillip Drew Incorporated, London.

Merrill Lynch, *Currency & Bond Market Trends: A Biweekly Review*

S.G. Warburg, *Weekly International Bond Market Review*

Goldman Sachs, *International Economic Indicators Calendar*

Note:
Release dates were cross-checked using the above sources. The Phillip Drew data was the most reliable. However, it does not begin until late 1988. Further, the German release dates from the last three sources are highly unreliable. Consequently, Deutsche mark returns were restricted to the 1/89 - 12/90 period and only German information release dates obtained from Phillip Drew were used.

Monetary Balance of Payments Model: The MBP model is most useful in understanding the general pressures on exchange rates and the possible direction of change. However, the model is not particularly useful in predicting what the exchange rate will be in either the near term or long run since it is possible for imbalances to exist for very long periods of time. The model focuses on two major categories of payments: those that are for business and consumption purposes (autonomous), and those undertaken by a government to finance a deficit or surplus in balance of payments. At the core of the MBP model, however, are two basic building blocks — the purchasing power parity relationship and the demand for money — and how they will affect exchange rate movements.

3.4.2 *Merchandise Trade Balance*

If the monetary balance of payments model is viewed as the primary exchange rate valuation model, then surprises in the merchandise trade balance between two countries should affect exchange rates. A larger than expected U.S./Japan trade deficit should cause the dollar to devalue relative to the yen. The merchandise trade balance is released monthly in the U.S., generally as a joint announcement with industrial production.

3.4.3 *Industrial Production*

Monthly announcements of industrial production may influence estimates of real economic growth. If the announced industrial production is greater than expected, it may cause economic agents to forecast a more restrictive Federal Reserve policy in the future if such surprises are correlated with future inflation or money growth. In this case, if the public perceives that the Federal reserve will not accommodate these increases, interest rates may rise. The effect on exchange rates will depend on perceptions of relative changes in the foreign interest rates. Industrial production announcements in the U.S. are made monthly, generally as a joint release with the merchandise trade balance.

3.4.4 *Money Supply Announcements*

Unexpected growth in the money supply is associated with higher interest rates.[25] There are two opposing explanations of this result. First, market participants may believe that the

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[25] See Grossman (1981), Urich and Wachtel (1981), Roley (1983), and Cornell (1983) for empirical studies of the relationship between growth rate in the money supply and interest rates.

Table 3.3

Summary of Studies of the Impact of Macroeconomic News on Prices

Study	Variables Examined		Summary
Hakkio & Pearce (1985) • Asset: Spot Currencies BP, SF, DM, JY, CD, FF, IL • Period: 1977-84	IP MS CPI PPI RU	 ✔	They use 9:00 a.m., 12 noon, and 4:30 p.m. spot exchange rates and examine the change related to unexpected news. Their results indicate that exchange rates are systematically related to unexpected money supply announcements. The timing of the RU announcements are identical to CPI and PPI.
Ito & Roley (1987) • Asset: Spot JY • Period: 1980-85	IP MS PPI	✔ ✔	They looked at macroeconomic "surprises" in the U.S. and Japan and the effect on $/Yen <u>trading</u> period returns in each market as well as <u>non-trading</u> period returns when both markets are closed.
Harvey & Huang (1991) • Asset: Currency Futures BP, SF, DM, JY, CD • Period: 1980-88	CPI PPI CU RU GNP PI PE LI	 ✔ ✔ ✔	They performed no direct tests on which variables had a specific impact. In addition, they looked only at U.S. variables. They also speculated that high Friday opening variance might be due to 3:30 p.m. Thursday release of money supply, when in fact this will be reflected in the subsequent non-trading period variance.
Cornell (1983) • Asset: Interest Rates • Period: 1978-81	MS	✔	Cornell examined the impact of money supply announcements on the bond market (e.g., interest rates) for the entire term structure, long and short-term.
Castanias (1979) • Asset: Stocks • Period: 1973-77	CPI PPI		Castanias found a lack of increased variance around these two macroeconomic variables (using the dummy variable method, but no differentiation between expected and unexpected). However, the results did show that the variance of stock prices increased around <u>days</u> of <u>most</u> economic news events.
Schwert (1981) • Asset: Stocks • Period: 1953-78	CPI	✔	The stock market reacts to unexpected inflation around the time CPI is announced, rather than when the CPI is sampled, several weeks before the announcement date. Therefore, the announcement does provide information to the market.
Pearce & Roley (1985) • Asset: Stocks • Period: 1977-82	IP CPI MS DR	✔ ✔	They used survey data to determine the *ex post* unexpected component of the announcements (i.e., only surprise moves <u>daily</u> stock prices — as per the efficient market hypothesis).

A check mark (✔) by a variable indicates support for that variable was found. The table continues on the following page, where abbreviations used are defined.

Table 3.3 Continued

Study	Variables Examined	Summary
Jain (1988) • Asset: Stocks • Period: 1978-84	IP CPI ✔ MS ✔ PPI UR	Prem examines the response of hourly stock returns and trading volume to macroeconomic announcements (Pearce & Roley's data). The results indicate that trading volume is not affected by any of the macro-variables, indicating that market participants do not differ significantly in their interpretations of the effects of the announcements. In addition, the results indicate that the effect on prices is reflected in about an hour or so.
Cutler, Poterba, & Summers (1989) • Asset: Stocks • Period: 1926-85	IP ✔ MS CPI ✔ GNP	They treat residuals from expectations formed from time series regressions on past variables as macroeconomic news and use them as explanatory variables. They found that inflation had a statistically negative impact on monthly stock returns.
Shanken & Weinstein (1990) • Asset: Stocks • Period: 1958-83	IP ✔ CPI	They use a two-pass regression methodology on monthly data to estimate betas for various factors, including two macroeconomic variables. They find statistically significant support for pricing of the percentage change in industrial production.
Ederington & Lee (1992) • Assets: T-Bond, Eurodollar, and DM futures markets • Period: 11/88-11/91	RU* ✔ MTB ✔ PPI* ✔ DG ✔ GNP*✔ RS ✔	They use data over five minute intervals to examine the impact of macroeconomic news releases on volatility. Out of 20 U.S. macro-variables, they find these six to have significant impacts on DM futures (those marked with an asterisk also had a significant impact on T-Bond and Eurodollar futures markets).

A check mark (✔) by a variable indicates support for that variable was found.

Abbreviations used for macroeconomic variables and their release intervals are:

MTB = merchandise trade balance (Mo)
IP = industrial production (Mo)
MS = money supply (Wk)
CPI = consumer price index (Mo)
PE = plant & equipment expenditures (Qtr)
DR = discount rate (Wk)
RS = retail sales

PPI = producer price index (Mo)
CU = capacity utilization (Qtr)
RU = rate of unemployment (Mo)
GNP = gross national product (Mo)
LI = leading indicators (Mo)
DG = durable good orders (Mo)

Abbreviations used for currencies are:

BP = British pound
SF = Swiss franc
DM = Deutsche mark
JY = Japanese yen

CD = Canadian dollar
FF = French franc
IL = Italian lire

Federal reserve will react to unexpectedly high money growth by quickly moving to a more restrictive monetary policy, which would in turn lead to higher interest rates. Second, market participants may revise upward their expectations of inflation when a positive money supply surprise occurs, which in turn leads to higher interest rates. Either explanation could lead to changes in exchange rates through either the IRP or PPP models of exchange rates.

When the Fed announces a money supply greater than had been expected, interest rates rise. Why? One explanation is that the market raises its estimate of the future rates of money growth and inflation, and bids up nominal interest rates. Engle and Frankel (1984) offer contrary evidence: on such days the dollar appreciates, not depreciates. An alternative explanation is that the market perceives the change in the money stock as a transitory fluctuation that the Fed will reverse in the future. The anticipated future tightening raises today's real interest rates, causes a capital inflow, and appreciates the dollar — the result which is in fact observed. In terms of exchange rates, the important result is that when the Fed announces an increase of the money supply greater than had been previously expected, the value of the US dollar increases (along with interest rates). In summary, the money growth announcement causes the real interest rate to rise, which explains <u>both</u> the rise in the nominal interest rate and the fall in the dollar exchange rate [Engle and Frankel (1984)].

3.4.5 *Consumer Price Index*

A much publicized economic announcement is the monthly report on the rate of inflation measured in the previous month. Schwert (1981) found that the stock market reacts to unexpected inflation around the time the CPI is announced, rather than when the CPI is sampled, several weeks prior to the announcement. Schwert concludes that there is evidence the Bureau of Labor Statistics provides valuable information to the market by collecting and assimilating observable prices into a single index number. Thus, CPI announcements can lead to changes in exchange rates through the PPP model as market participants revise their expectations of relative inflation rates between the U.S. and foreign countries.

3.5. Summary

In this chapter the data set used and the methodology employed have been presented. The data consists of opening and closing spot and futures currency quotes over the period January, 1988 – December, 1990 — which allows the partition of the 24-hour day into a U.S. trading period and non-trading period. The variance-rate ratio is used to compute F-statistics which allow tests of variance differences between trading and non-trading periods (as well as conditional on the presence or absence of scheduled U.S. or foreign macroeconomic news releases). In addition, four diffusion and jump-diffusion models of currency returns are developed — both with and without variance terms conditional on the release of macroeconomic news. The likelihood ratio test of nested models as a means of evaluating the relative ability of the four models to explain the currency return process is presented. Finally, brief explanations as to why each of the four macroeconomic variables chosen to represent news may have an impact on exchange rates are given.

CHAPTER 4

TESTABLE HYPOTHESES

Three possible explanations for higher return variances during trading hours have been advanced by French and Roll (1986):

- *Public Information Hypothesis*. Variances are higher during trading hours because public information is more likely to be released during normal business hours.
- *Private Information Hypothesis*. Volatility patterns are due to private information being revealed through trading, which can only take place when exchanges are open.
- *Pricing Errors Hypothesis*. Volatility patterns may be caused by pricing errors that are generated by the trading process.

French and Roll conclude that for the stock market the higher trading period volatility is primarily due to the revealing of private information through trading. However, they are able to come to this conclusion by relying on the fact that when the U.S. stock market is closed most of the listed stocks do not trade elsewhere. As noted in Section 3.1, the foreign exchange market is open virtually 24-hours a day and is characterized by electronic trading and a succession of overlapping business hours. Thus, tests of the public information hypothesis for currency markets need to examine the impact of foreign news releases as well as U.S. news releases. This study examines the impact of U.S. and foreign macroeconomic information releases on the volatility of three major foreign exchange rates relative to the dollar. In addition the volatility is examined in both spot and futures currency markets. In this chapter the hypotheses of currency market volatility which are testable using the methodology of this study are set forth.

4.1 Variance Ratio Testable Hypotheses

For both the spot and futures markets, the variance during the U.S. trading period should be greater than that during the non-trading period (when foreign markets are open). All exchange rates used in this study are expressed with the dollar as the numeraire. Thus, the relationship of greater volatility during the U.S. trading period should hold if U.S. information released during the U.S. trading period dominates foreign information released during the non-trading period.

The variance during morning trading hours should be greater than the variance during afternoon trading hours.[1] Three of the four U.S. macroeconomic information releases used in this study are released in the morning (see Table 4.1). Money supply is the only macro variable which is released in the afternoon (at 4:10 p.m.) and thus will be reflected in the subsequent non-trading period variance because the "trading period" for this study ends at 3 p.m.

Finally, if U.S. news releases do have a greater impact on currency market volatility, then trading period variance on days of U.S. macroeconomic announcements should be greater than non-trading period variance on days of equivalent foreign macroeconomic announcements. Thus, the T/NT variance ratio conditional on the release of both U.S. and foreign news should be greater than one.

4.2 Likelihood Ratio Testable Hypotheses

If the inclusion of a variance term conditional on the release of macroeconomic news better describes the currency return process, then the log-likelihood value for the model with the conditional variance term should be larger (i.e., closer to zero). The four diffusion and jump-diffusion process models are summarized in Figure 4.1 — which shows that Models II, III, and IV can all be tested against the simple diffusion process of Model I. Similarly, Model IV can be tested against Models II and III. In the case of Model IV against Model II, what is being tested is whether a jump process in addition to a conditional variance term better describes the currency return process. Finally, testing all these models conditional on all or just one of the four

[1] See Figure 3.2 for the exact times of the morning and afternoon subperiods. This hypothesis can only be tested in the spot market because mid-day price quotes for the trading period were only available for the spot market.

macroeconomic variables allows tests of whether that variable has a significant impact on currency volatility over the period studied.

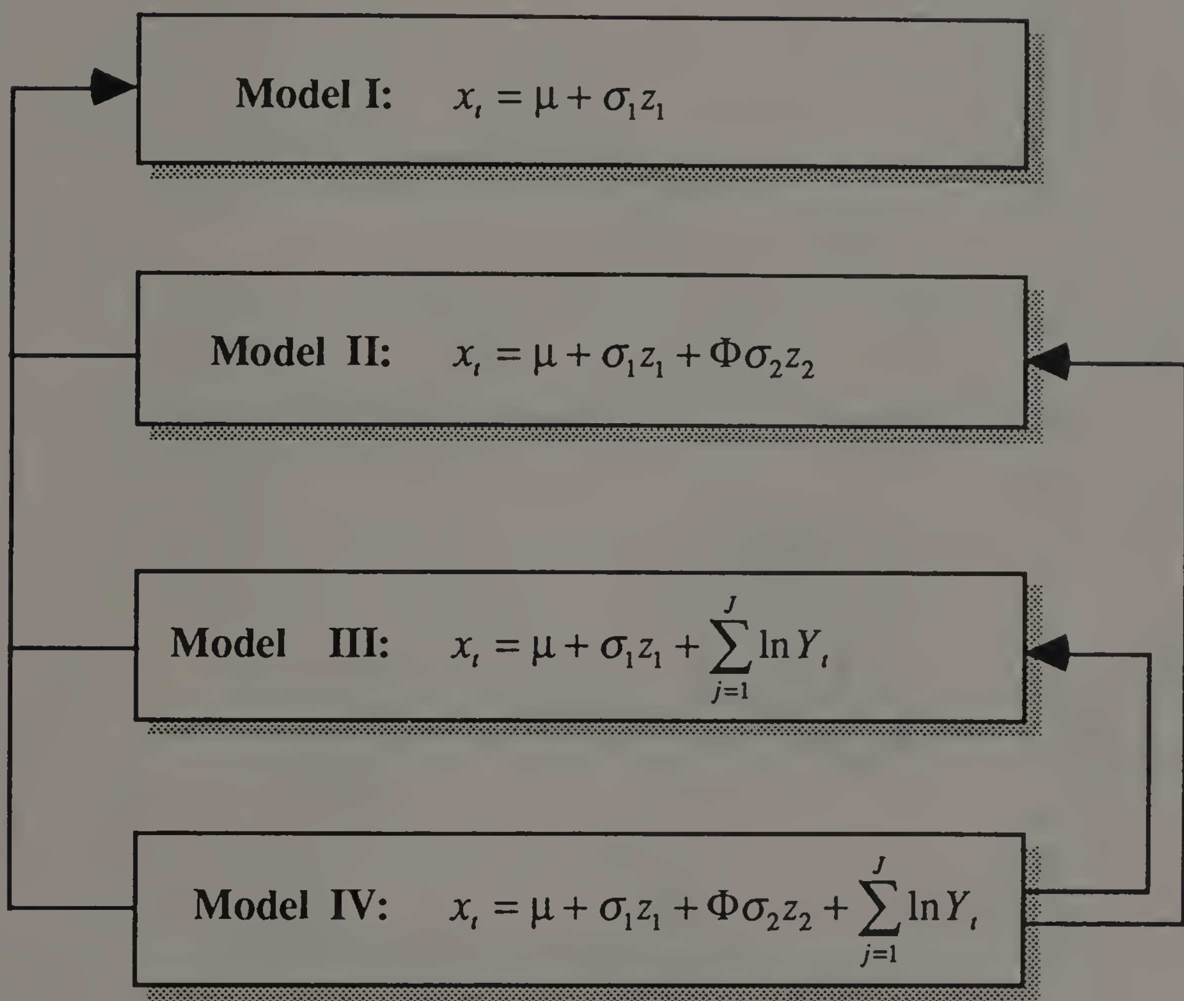

Figure 4.1: Summary of Models, and Hypotheses Which can be Tested Using Nested Likelihood Ratio Tests

The models are tested against each other using the likelihood ratio test:

$$-2\left[\ln L(\gamma_0\,;x) - \ln L(\gamma_A\,;x)\right] \sim \chi^2_\eta$$

where η is the number of parameters restricted to zero in the null (nested) hypothesis model (e.g., when testing Model II against Model I, σ_2 is restricted to zero and $\eta = 1$). The arrows in the above diagram indicate the null hypothesis model which the other models can be tested against. The models describe:

Model I:	a simple diffusion process,
Model II:	a diffusion process with a conditional variance term,
Model III:	an unconditional mixed jump-diffusion process,
Model IV:	a mixed jump-diffusion process with conditional variance.

CHAPTER 5

RESULTS

In Section 5.1 results obtained from traditional variance ratio tests of trading/non-trading period volatility are presented. In Section 5.2, results obtained from maximum-likelihood (ML) estimation of diffusion and jump-diffusion process models are presented. All tables are placed at the end of the chapter to improve readability. However, where appropriate, graphs have been constructed using selected information in the tables to illustrate and help clarify important results and are presented as they appear in the chapter, rather than at the end. Section 5.3 summarizes the results

5.1 Variance Ratio Results

General relationships between trading and non-trading volatility and macroeconomic announcements are presented in Section 5.1.1. In Section 5.1.2, the relationship between news releases and volatility clustering are further explored by looking at variance ratio results which are conditioned on the release of news. The length of time that increased volatility persists after public news is released is examined in Section 5.1.3 by comparing the volatility during morning and afternoon U.S. trading-time sub-periods.

5.1.1 *Trading/Non-Trading Period Volatility*

In Table 5.1, results are presented for currency spot and futures trading and non-trading period return variances over the three-year 1988-1990 period studied. Variance rates and variance-rate ratios are reported on a daily basis as well as a simple average across all five trading days of the week. In accordance with the information hypotheses of French and Roll (1986) trading period variance should be greater than non-trading period variance if any of the following three hypotheses hold: (1) there is a concentration of *public information* releases during trading time, (2) *private information* is incorporated into prices during trading time, or (3) *pricing errors* are generated by the trading process. All but three of the spot and futures trading/non-trading (T/NT) variance ratios shown in Panel C of Table 5.1 are significantly greater than one at the 1% level.[1] These results are consistent with those of Ito and Roley (1987), Hertzel, Kendall, and Kretzmer (1990), Harvey and Huang (1991), and Joines, Kendall, and Kretzmer (1990) — who all find that the trading period variance is higher than the non-trading variance for both spot and futures currency markets.[2]

The private information hypothesis is not the likely explanation for the observed variance differential because, unlike stock markets, the spot currency market is a liquid, 24-hour market — which means participants do not have to wait until the U.S. trading period to trade on private information. The public information hypothesis is the more likely explanation for the difference in relative variance rates. In contrast to the stock market, the determinants of foreign exchange rates generally consist of publicly available information. Public information released during the respective trading hours in both countries will likely have an influence on the volatility of the two countries' exchange rate. Thus, volatility is expected to be concentrated during the times when the most relevant macroeconomic news is released.

The daily trading and non-trading variance rates from Panels A and B in Table 5.1 are graphed in Figures 5.1 and 5.2 (on the next two pages, futures and spot respectively). As can be seen from the graphs, trading and non-trading period variances are not constant across days of

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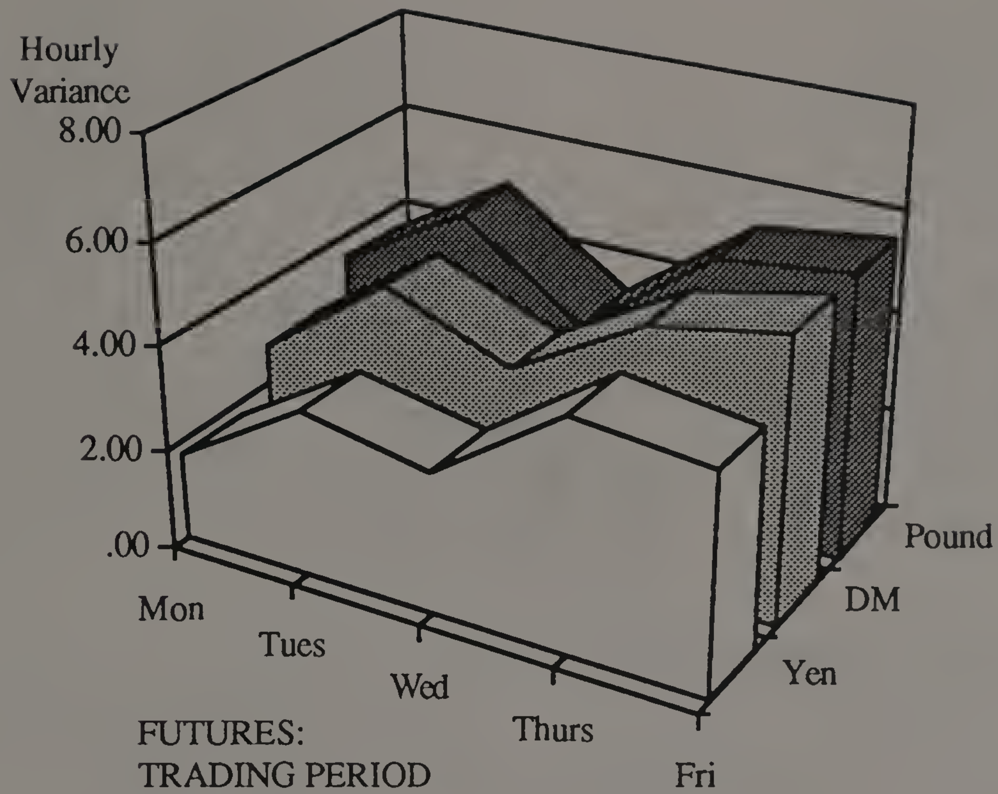
[1] In the interest of readability, T/NT will often be used to abbreviate "trading/non-trading." Similarly, other abbreviations, such as AM/PM, will be used to abbreviate other periods and will be defined as they appear.

[2] None of the authors examined both the spot and the futures currency markets. Ito and Roley (1987) used data from the spot currency market, all the other authors used data from currency futures markets — probably because obtaining open and close data for U.S. futures markets is much easier than for the spot market.



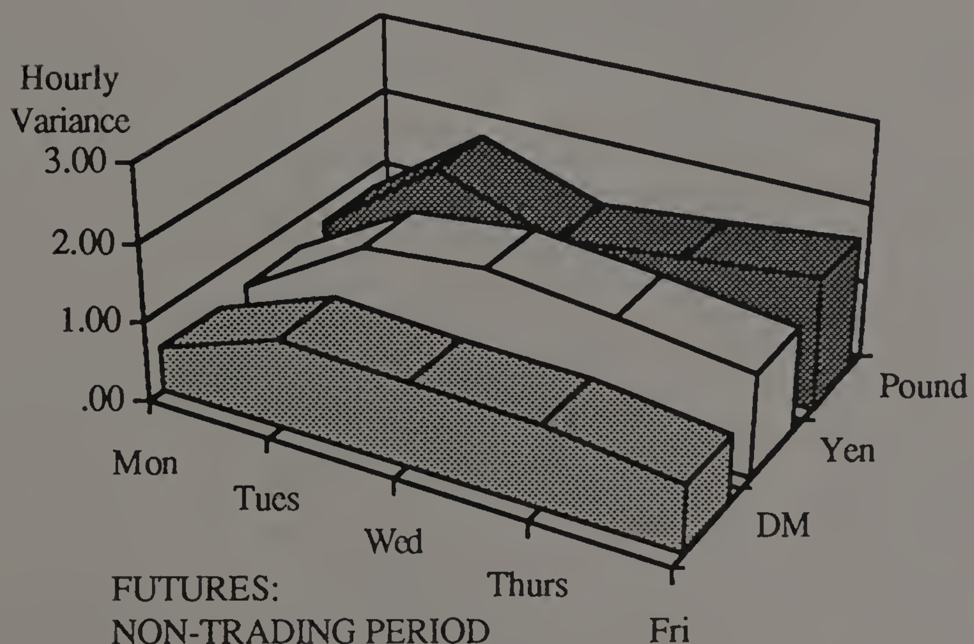
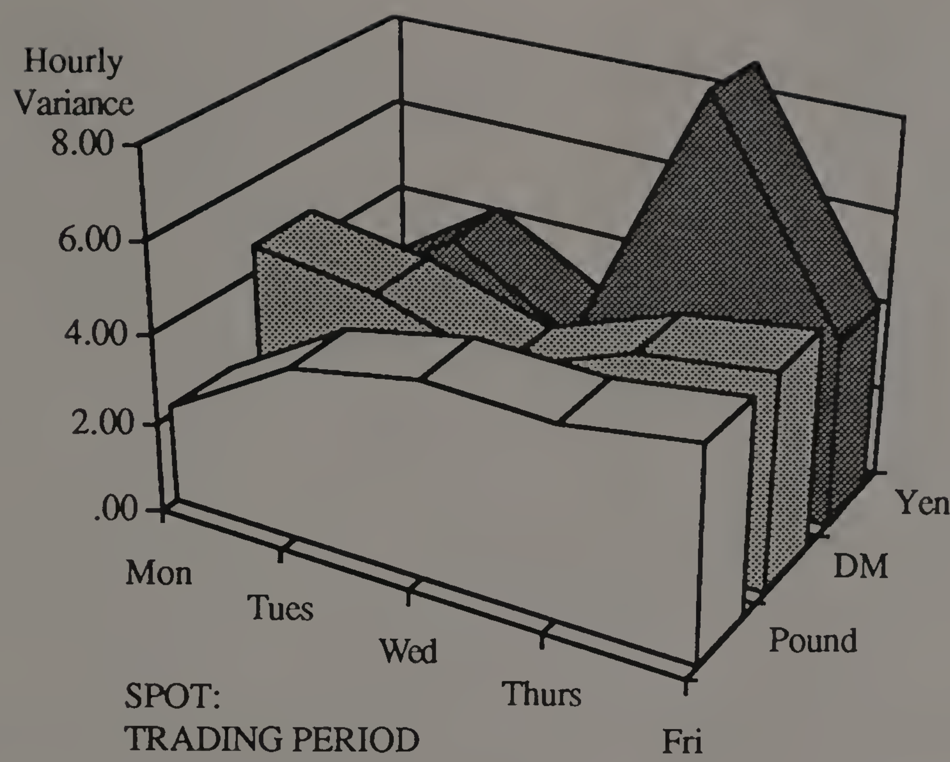


Figure 5.1: Interday Currency Futures Volatility

Shown are trading and non-trading hourly variance rates for log-returns on the nearest to delivery CME currency futures contract. The variances are also scaled by 10^6 (e.g., multiplied by 1,000,000). The sample period is from January 4, 1988 to December 31, 1990. The vertical scale for the non-trading period variances is exaggerated relative to that of the trading period. The order of the DM and yen is also reversed to provide a clearer graph.



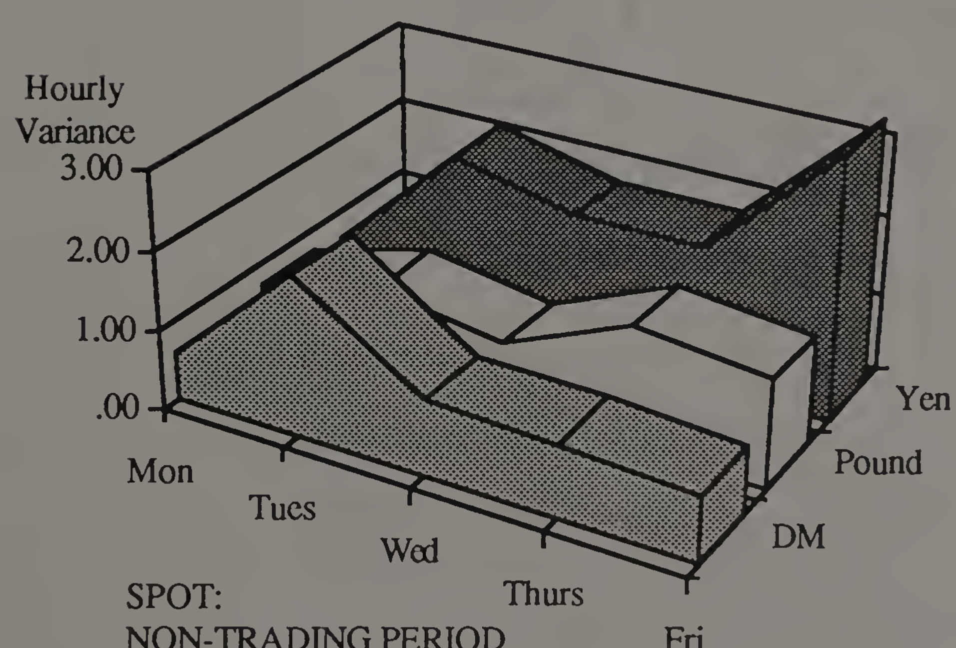


Figure 5.2: Interday Spot Currency Volatility

Shown are trading and non-trading hourly variance rates for log-returns on the spot currency. The variances are also scaled by 10^6 (e.g., multiplied by 1,000,000). The sample period is from January 4, 1988 to December 31, 1990. The vertical scale for the non-trading period variances is exaggerated relative to that of the trading period. The order of the DM and pound is also reversed to provide a clearer graph.

the week and exhibit decided patterns.[3] The inter-day pattern of trading period variance for the futures market — high on Tuesday, Thursday, and Friday and low on Monday and Wednesday — is similar for all three currencies studied. The inter-day variance patterns for the spot market trading period, however, are much less consistent for the three currencies — especially the yen. There do not seem to be similarities in the non-trading period variance patterns for the three currencies, in either the spot or futures markets.

If the public information hypothesis is the correct explanation for patterns in daily variances, the trading period pattern for all three currencies should be similar — because there is one common source of public news (U.S. macroeconomic announcements) which should influence all three exchange rates during the trading period. Similarly, the public information hypothesis implies that the currencies might be expected to display different non-trading period variance patterns because there are three different sources of public information (macroeconomic announcements for Britain, Japan, and Germany) which should influence each of the respective currencies during the non-trading (foreign) period.

In Table 5.2, the concentration of U.S. and foreign monthly macroeconomic announcements on different days of the week are given.[4] The macroeconomic variables used in this study, previously detailed in Section 3.4., are: merchandise trade balance (MTB), industrial production (IP), money supply (MS), and consumer price index (CPI). The daily pattern of monthly U.S. macroeconomic releases (MTB, IP, CPI) is graphed in Panel A of Figure 5.3. — which shows that the concentration of announcements is highest on Tuesdays and Fridays and lowest on Mondays. There are 156 weekly MS releases during the period of this study. If they are included, then Thursday has by far the highest concentration of announcements (although

[3] Although not tested here, Harvey and Huang (1991) used a Chi-square test of variance equality from a GMM estimation of variance and rejected the hypothesis that exchange-rate returns in the futures market were equal over days of the week for the 1980-88 period.

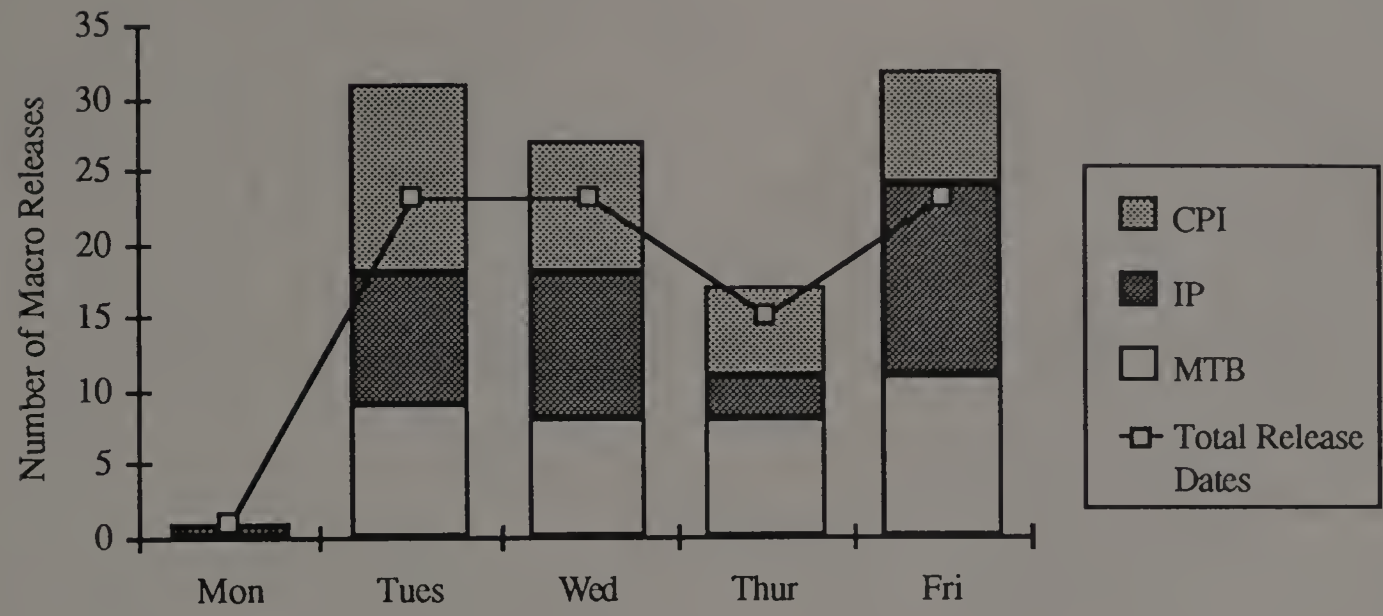
[4] Weekly U.S. money supply announcement dates are not included in the table. U.S. money supply is always announced at 4:10 p.m. each Thursday. Thus, including it in any table or graph of the distribution of announcements across days of the week would render the comparison useless because of the large number of MS announcements (156) compared to each of the other announcements (36) in this study.

the MS releases occur at 4:10 p.m., after the closing 3:00 p.m. spot quote and 2:20 p.m. futures price).

The inter-day trading time volatility patterns in the currency futures market, shown in Figure 5.1, are consistent with the concentration of monthly U.S. macroeconomic announcements (i.e., excluding MS). High variance on Tuesday, Thursday, and Friday coincide with high concentrations of announcements on those days. In the spot market the patterns are considerably different. The yen and pound have lower trading period volatility on Monday, which is consistent with the almost complete lack of announcements. In contrast, the mark has a high volatility on Monday. The most puzzling spot market result, however, is the yen's Thursday trading time volatility — which is more than double the volatility of any other day. In contrast, no similar increase in volatility is seen on Thursday for the pound or mark — or for all three currencies in the futures market.

The reason for the yen's unusual Thursday behavior — high volatility in the spot market, but not in the futures market — could be the result of different spot and futures market characteristics and the timing of macroeconomic announcements. First, there is the fact that no organized currency futures exchange existed in Japan during the three-year period of this study. Consequently, any traders wishing to take a position based on private information or an educated guess about a macroeconomic announcement occurring late in the U.S. trading period will do so in the spot market rather than the futures market — where *unwinding* a futures position in the subsequent non-trading period would be impossible due to the lack of a Japanese futures market. Second, the yen accounts for 90 percent of the spot market trading in Japan. Thus, near the end of the U.S. trading period, traders wishing to take a currency position in anticipation of the soon to be released U.S. money supply figure, will do so in the yen — rather

Panel A:
Number of U.S. (Trading Period) Monthly Macroeconomic Announcements Occurring on Each Day of the Week



Panel B:
Percentage of Foreign (Non-Trading Period) Macroeconomic Announcements Occurring on Each Day of the Week

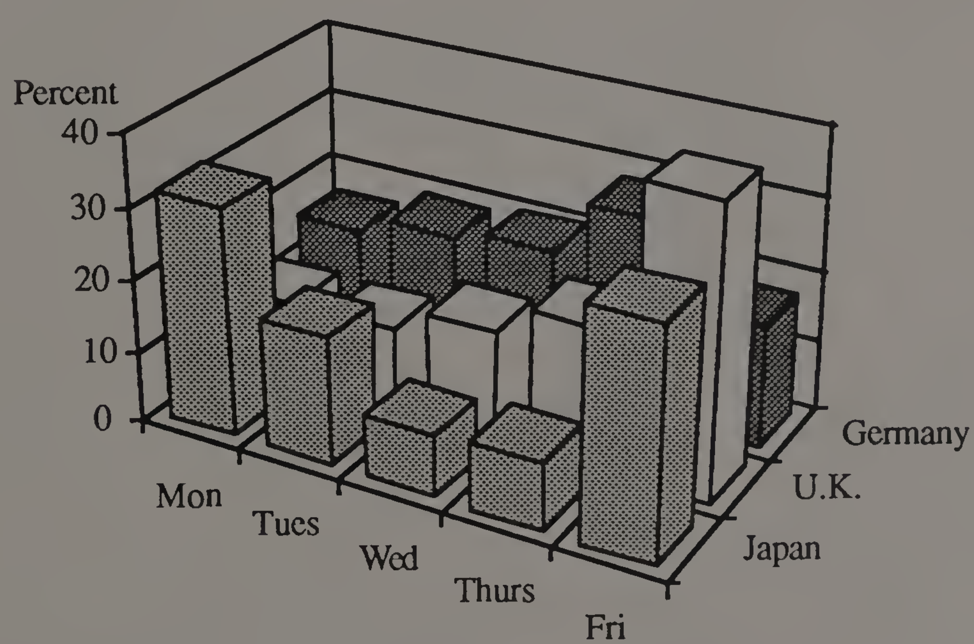


Figure 5.3: Distribution of Macroeconomic Releases

Shown in Panel A are the number of monthly U.S. macroeconomic releases by day of the week. "Total Release Dates" are the number of release dates, where a date is counted once, even if two or more of the macroeconomic variables in this study are announced. U.S. money supply releases are not graphed since all 156 occurred at 4:10 p.m. each Thursday, after the close of the trading period as defined in this study. Thus, any impact from U.S. money supply release will appear in the Friday non-trading period. Shown in Panel B are the percentage of all four foreign macroeconomic releases for a given country which occurred on each day of the week (where each release is counted, even if more than one occurred on a given day). Abbreviations for the macroeconomic variables are: *CPI* = consumer price index, *IP* = industrial production, and *MTB* = merchandise trade balance. These release dates include all years from 1988 through 1990 — except Germany, which includes 1989 through 1990.

than the pound or mark — so they can unwind their positions in the yen's more liquid spot market during the Japanese trading period.[5]

The volatility patterns in Figure 5.1 and 5.2 seem to support the market-characteristic/ announcement-timing explanation for the Yen's high spot market volatility on Thursdays. As can be seen in the table below, the Thursday afternoon increase in hourly spot-market variance is greatest for the yen.

Thursday:	AM	PM
Yen	.0292	.1122
Pound	.0258	.0619
DM	.0313	.0511

Thus, it appears that the increase in yen volatility could be due to the anticipation of the 4:10 p.m. U.S. money supply announcement — as traders with inside information or the belief that they have superior hunches take the appropriate position in the yen spot market, expecting to unwind their positions in the very liquid Tokyo yen spot market. In contrast, the pound and mark exhibit only small increases in Thursday afternoon volatility. Further evidence for this explanation is the fact that all three currencies have equivalent Thursday futures-market variances, shown in Figure 5.1, indicating that traders may choose not to take positions in the futures market Thursday afternoon which could not be unwound until the Chicago market opens Friday morning.[6] Finally, the Japanese yen non-trading variance is much higher on Friday in the spot market, but not the futures market. The higher variance in the spot market may be due to volatility induced by traders unwinding the positions they took in the U.S. currency market before the money supply announcement. This explanation appears to solve the puzzle of the

[5] There could be other explanations for this pattern in the Thursday/Friday yen spot market volatility. (1) Over the period of this study, Japanese institutions were often large buyers in the U.S. 30-year treasury market. Since the results of the Treasury auction become known once a quarter on a Thursday afternoon, Japanese institutions might take a position in the currency spot market based on the level of currency movements required for the purchase of U.S. T-bonds — e.g., hedge the currency flow. (2) During part of the three-year period of this study, market participants focused on the employment figure (as a predictor of industrial production, and also the trade balance). The employment figures are released the first Friday of each month. Thus, there could potentially be an anticipatory effect (if there were some leakage) on Thursday afternoon in the U.S. and Friday morning in Japan.

[6] In addition, CME currency futures trading closes at 2:20 p.m. EST, while the closing price used for the spot market in this study is 3:00 p.m. EST. Thus, the closing spot price is more likely to reflect an anticipation effect since it is closer to the 4:10 p.m. announcement.

yen's spillover volatility from the U.S. Thursday afternoon to the Japanese Friday period.[7] More importantly, it provides evidence that the commonly held belief that new information is always reflected in futures markets before spot markets may not always hold.[8]

Foreign non-trading period macroeconomic releases, shown in Figure 5.3, are not uniformly distributed across days of the week. Japanese announcements are concentrated on Mondays and Fridays — with about 32% of total announcements occurring on each of those two days. The concentration of U.K. announcements is lowest on Monday and increases each day as the week progresses — with Friday accounting for 40% of total announcements. The concentration of German releases is similar to that of the U.K. (increasing as the week progresses) except that the concentration of announcements peaks on Thursday (28%) and declines sharply on Friday (17%).

The inter-day non-trading period variance patterns for the futures market, shown in Figure 5.1, are very similar for all three currencies. However, the patterns do not seem to conform to the distinctly different patterns in concentration of macroeconomic announcements for the three currencies shown in Figure 5.3. Patterns of inter-day variance shown in Figure 5.2 for spot market non-trading periods are not at all similar for the three currencies. As was previously noted, the yen's large increase in Friday NT variance may be due to the Thursday afternoon U.S. money supply announcement. The yen's low Monday variance, however, is not consistent with the high concentration of Japanese macroeconomic releases on Monday. The pound's spot variance does seem to follow the distribution of U.K. macroeconomic releases — variance at the end of the week is higher than at the beginning of the week, which is consistent with the concentration of announcements later in the week. The DM volatility pattern is the opposite of

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[7] Ito and Roley (1987) showed evidence of the spillovers into the Pacific market after weekly money supply announcements. However, they did not look at volatility spillovers. In addition, Harvey and Huang (1991) believe that high Friday morning opening volatility in the U.S. futures markets may be due to a spillover from the Thursday money supply announcement after the close of futures trading. In fact, they are asserting that the spillover skips the Pacific and Europe markets and shows up in the following day's trading period. The analysis here suggests that this is almost certainly not the case.

[8] This pattern provides one contradiction to studies by Cornell and Reinganum (1981) and Hodrick and Srivasta (1987) who all conclude that there is a close association between the spot (OTC) market and the futures market for currencies.

what the concentration of German macroeconomic announcements would suggest. Volatility is highest on Tuesday (a day with an average number of announcements) and no higher than usual on Thursday (which has the highest concentration of announcements).

In summary, the results from simple variance ratio tests, combined with the patterns of inter-daily variance and macroeconomic announcements, have shed some light on the relationship between news and currency market volatility. First, T/NT variance ratios indicate that either more information is generated during U.S. trading time, or that U.S. information releases have a greater impact on currency variance than does foreign information.[9] Moreover, this result holds for both the spot and futures markets. In addition, the results demonstrate that trading and non-trading variance patterns are different between the spot and futures markets. The trading period variances for the futures market appear to conform to the distribution of macroeconomic announcements. The variance patterns for the DM and pound spot variances also seem to follow a pattern similar to their respective announcements. However, the yen has an unusually large variance on Thursday. The explanation of a possible Thursday trading-period anticipatory effect due to the U.S. money supply announcement, carrying over into Friday's NT-period variance has some interesting implications. It indicates that public information is not always reflected first in the futures market as is commonly asserted. Instead, market liquidity differences (e.g., the yen accounts for 90 percent of Tokyo spot trading) and the timing of the announcement (e.g., U.S. money supply is announced at 4:10 p.m., after U.S. trading has wound down) are factors that seem, in specific instances, to influence which market traders prefer and therefore reflects public information first.

[9] These results are in agreement with those of previous authors: Ito and Roley (1987), Hertzel, Kendall, and Kretzmer (1990), Harvey and Huang (1991), and Joines, Kendall, and Kretzmer (1990). However, with the exception of Ito and Roley, none of the other authors examine the effect of foreign macroeconomic announcements.

5.1.2 *Variance-Ratio Results: Conditional on the Release of News*

In Section 5.1.1, daily variance rates and variance ratios were presented. In addition, the relative frequency of U.S. and foreign macroeconomic releases across the days of the week was examined as a first pass at explaining the inter-day volatility in the spot and futures exchange rate markets. In this section, several different variance ratios (e.g., T/NT, NT/T) which are conditional on the presence or absence of U.S. or foreign macroeconomic releases are used to more carefully examine the link between public news and exchange rate volatility.[10]

In Table 5.3, variance ratios are presented for days of (1) no macroeconomic release — U.S. or foreign, (2) U.S. but no foreign macroeconomic release, and (3) foreign but no U.S. macroeconomic release.[11] Results are presented on a pooled basis (e.g., all days) as well as on a day-of-the-week basis. If the public information hypothesis is correct, variance during periods when macroeconomic announcements are made should be higher than contemporaneous periods with no announcements. Thus, trading period variance rates on days of U.S. announcements should be greater than NT variance rates on days of no foreign announcements. Similarly, NT variance rates on days of foreign macroeconomic releases should be greater than trading period variance rates on days of no U.S. releases. The degree to which these hypothesized variance relationships hold or are violated provides some indication about the relative importance of U.S. and foreign macroeconomic news as well as the relative rate at which countries generate news which affects exchange rates.

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[10] Previous studies — e.g., Hertzel, Kendall, and Kretzmer (1990), Harvey and Huang (1991), and Joines, Kendall, and Kretzmer (1990) — have examined T/NT volatility. However, none of these studies addressed the volatility conditional on a specific set of news release dates. Thus, previous work has not progressed beyond simple relationships between macroeconomic release patterns and inter-daily variance patterns.

[11] Days of ***No macroeconomic release*** are those days when none of the four announcements in this study (MTB, IP, MS, CPI) were released in either the U.S. or the foreign country corresponding to the currency of interest — e.g., Japanese announcements and the yen. Similarly, days of ***U.S. but no foreign macroeconomic release*** are those when U.S. announcements were made during the trading period, but no foreign announcements corresponding to the currency of interest were made in the non-trading period. Finally, days of ***foreign but no U.S. macroeconomic release*** are those days when foreign non-trading period announcements were made in the country corresponding to the currency of interest, but no U.S. announcements were made in the trading period. There is obviously the possibility of a macroeconomic release which is not tracked in this study occurring on days of *U.S.*, *None*, or *Foreign* announcement. However, it is assumed that the other announcements either have little impact on exchange rates, or are randomly distributed across the sample (just as non-macroeconomic news items such as political events are assumed to be randomly distributed).

The results in Table 5.3 provide considerable support for the public information hypothesis. T/NT variance ratios on days of U.S. news are significantly greater than unity for the yen, pound, and mark in both the spot and futures markets for all days of the week.[12] In addition, the T/NT variance ratios on days of no U.S. or foreign news are almost all significantly greater than 1.0 in both markets for all three currencies. However, in every case, the no-news T/NT ratio is less than the U.S.-news T/NT ratio. The U.S.-news T/NT ratios pooled across all days of the week range from 3.0 to 6.7. The no-news T/NT ratios, however, are generally about half the size of the corresponding U.S.-news ratio. Thus, on days of no public news, as defined by the four macroeconomic variables in this study, the T/NT variance ratios for all three currencies are still greater than unity. This indicates that either (1) there are additional macroeconomic variables other than the four in this study that influence currency markets, or (2) there are factors other than public macroeconomic news which influence currency markets (e.g., political) and that they tend to cluster (or occur at a faster rate) during U.S. trading time rather than during non-trading time.[13]

The impact of foreign (i.e., Japanese, British, German) news on each currency's volatility is examined by inverting the usual T/NT variance ratio, and computing a NT/T variance ratio instead. If the public information hypothesis — with regard to foreign news — is correct, the NT/T variance ratio on days of foreign, but no U.S. news should be greater than unity. The results in Table 5.3, however, do not support this relationship. Daily NT/T variance ratios for all three currencies, in both the spot and futures markets, are between 0.18 and 0.66.[14] Thus, the non-trading period volatility on days of foreign macroeconomic news is less than the trading period volatility when no U.S. macroeconomic news is released. These results indicate that either (1) the foreign macroeconomic announcements which are defined as public news in this

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[12] The yen's Tuesday T/NT variance ratio on U.S. information days was the only one which was significant at the 5% level, but not the 1% level.

[13] For example, Cutler, Poterba, and Summers (1989) found that for the stock market, macroeconomic news accounted for only about one-third of the total volatility.

[14] Except the Friday spot market ratio for the yen of 3.8 — which, as previously noted, may be due to the 4:10 p.m. Thursday U.S. money supply announcement in the previous trading period.

study do not have a substantial impact on exchange rates, or (2) the impact of foreign news on exchange rates is not as great as the impact of U.S. news which is not includes in this study (e.g., U.S. news events other than the four macro-variables focused on here).[15]

The variance ratio results from Table 5.3 are summarized graphically in Figure 5.4 — which shows that trading time volatility is relatively greater than non-trading time on U.S.-news days. Although variance ratios are useful for testing hypotheses about relative volatility, useful information such as the absolute level of volatility is obscured. Levels of hourly variance for trading and non-trading periods on days of U.S., foreign, and no macroeconomic announcements are shown in Figure 5.5. The striking result shown in Figure 5.5 is that trading-period volatility exhibits considerable non-stationarity across news, no-news, and foreign-news days. However, with the notable exception of the spot yen, the absolute level of non-trading period volatility is relatively stable for all the currencies in the spot and futures markets.[16] In addition, non-trading period volatility for each currency is generally small compared to trading period volatility. This suggests that foreign macroeconomic news may have little impact on volatility, when compared to trading period volatility.[17]

Further evidence that U.S. macroeconomic news has a greater impact on exchange rate volatility than foreign news is provided in Table 5.4 — which reports T/NT variance ratios for trading period returns on U.S. announcement days and non-trading period returns on days of foreign announcements. The null hypothesis that the impact of U.S. and foreign news on volatility are equal (e.g., the T/NT variance ratio equals one) can be rejected at the one percent level on Tuesday and Wednesday for the mark (in both the spot and futures markets) and on Tuesday for the pound (in the futures market).[18] Furthermore, the T/NT variance ratios are

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[15] Where news is defined as the four macroeconomic releases used in this study.

[16] The yen's spot market NT variance results are driven entirely by the Friday NT volatility which — as has been postulated in Section 5.1.1 — may be due to the announcement of U.S. money supply in the immediately preceding Thursday trading period.

[17] However, it may be that foreign news has an impact on non-trading period volatility compared to days when no foreign news is released. This idea is examined in more detail in Section 5.3 — where the impact of specific macroeconomic announcements are examined, rather than the announcement dates as a set and trading and non-trading periods are considered separately.

[18] Variance ratios for Monday and Thursday could not be calculated because there is only one U.S. announcement which occurred on Monday, and all money supply announcements occur on Thursday. Thus, using

greater than one for all three currencies, in both the spot and futures market — ranging from 1.2 to 9.4. Thus, there is no evidence that foreign macroeconomic news has a greater impact on exchange rate volatility than U.S. news does.

In summary, the results from variance ratio tests between periods with and without the release of macroeconmic news indicate that U.S. news has a greater impact on exchange rate volatility than does foreign news. Thus, there is support for the public information hypothesis as a major determinant of exchange rate volatility during the U.S. trading period.

5.1.3 *Persistence of News Induced Volatility*

In the previous two sections results have been presented which indicate that U.S. macroeconomic news announcements do have an impact on trading-period currency volatility. In this section, the question addressed is how long the impact of macroeconomic news releases on volatility persists. Jain (1988) finds that most of the adjustment in stock prices to surprise in macroeconomic announcements occurs within one hour of the release.

The previous results in Tables 2 through 4 have generally supported the dominance of U.S. informational releases in the determination of inter-period trading/non-trading variance analysis. In Table 5 the U.S. trading period is decomposed into morning (8 a.m. - 12 noon) and afternoon (12 noon - 3 p.m.) sub-periods. For the United States the principal macroeconomic releases (CPI, IP, MTB) occur in the morning (although money supply is released on Thursdays after the afternoon period ends).

On days of no macroeconomic information release the variance-rate — after adjusting for the number of hours in each sub period — of the afternoon session (Monday through Thursday) is generally significantly greater than the variance of the morning session. The average of the daily morning to afternoon variance ratios for all days in which no macroeconomic information was released was .593 for the yen, .496 for the pound, and .442 for the mark. In contrast, for the yen, pound, and mark the morning variance for U.S. macroeconomic release days was

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the definition of U.S. release days (i.e., U.S. release, but no foreign release) and foreign release days (i.e., foreign release, but no U.S. release) results in a sample size of zero for both Monday and Thursday.

Panel A: Spot Currency Market

Panel B: Currency Futures Market

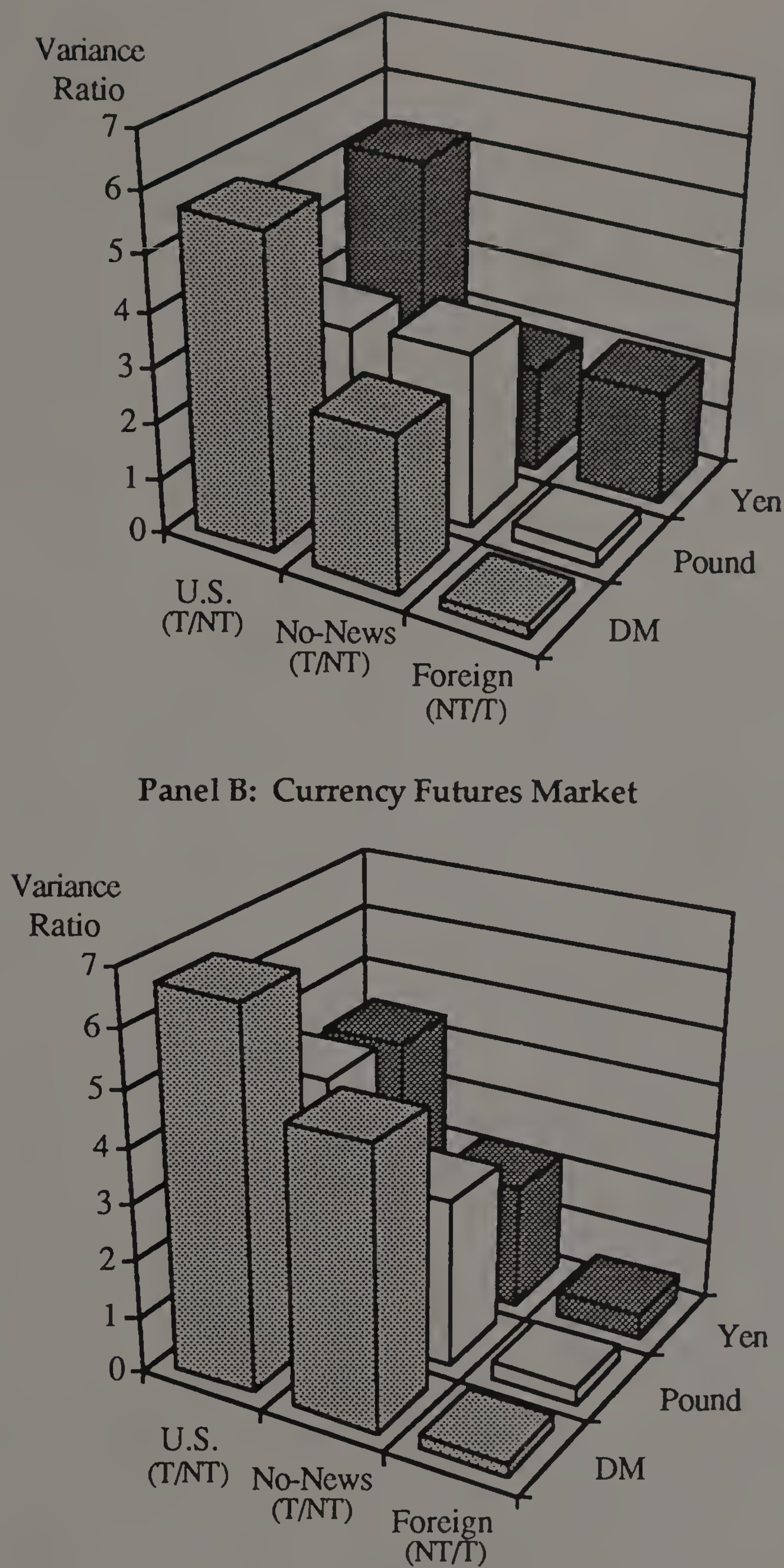

Figure 5.4: Variance Ratios: U.S. and Foreign Releases

Shown are T/NT and NT/T variance ratios on days of: (1) ***U.S.*** = U.S. release and no foreign macroeconomic release (for that country), (2) *No-News* = no U.S. or foreign release (for that country), and (3) ***Foreign*** = foreign release (for that country — e.g., Japan) and no U.S. release. For "U.S." and "No-News" macroeconomic announcements, the variance ratio is T/NT, while for "Foreign" announcements the variance ratio is NT/T — to test the hypothesis that non-trading variance on foreign release days is larger than trading variance on days of no U.S. release. Variance ratios are for hourly variance across all days of the week. The sample period is January 4, 1988 to December 31, 1990 — except for the DM, which is from January 4, 1989 to December 31, 1990.

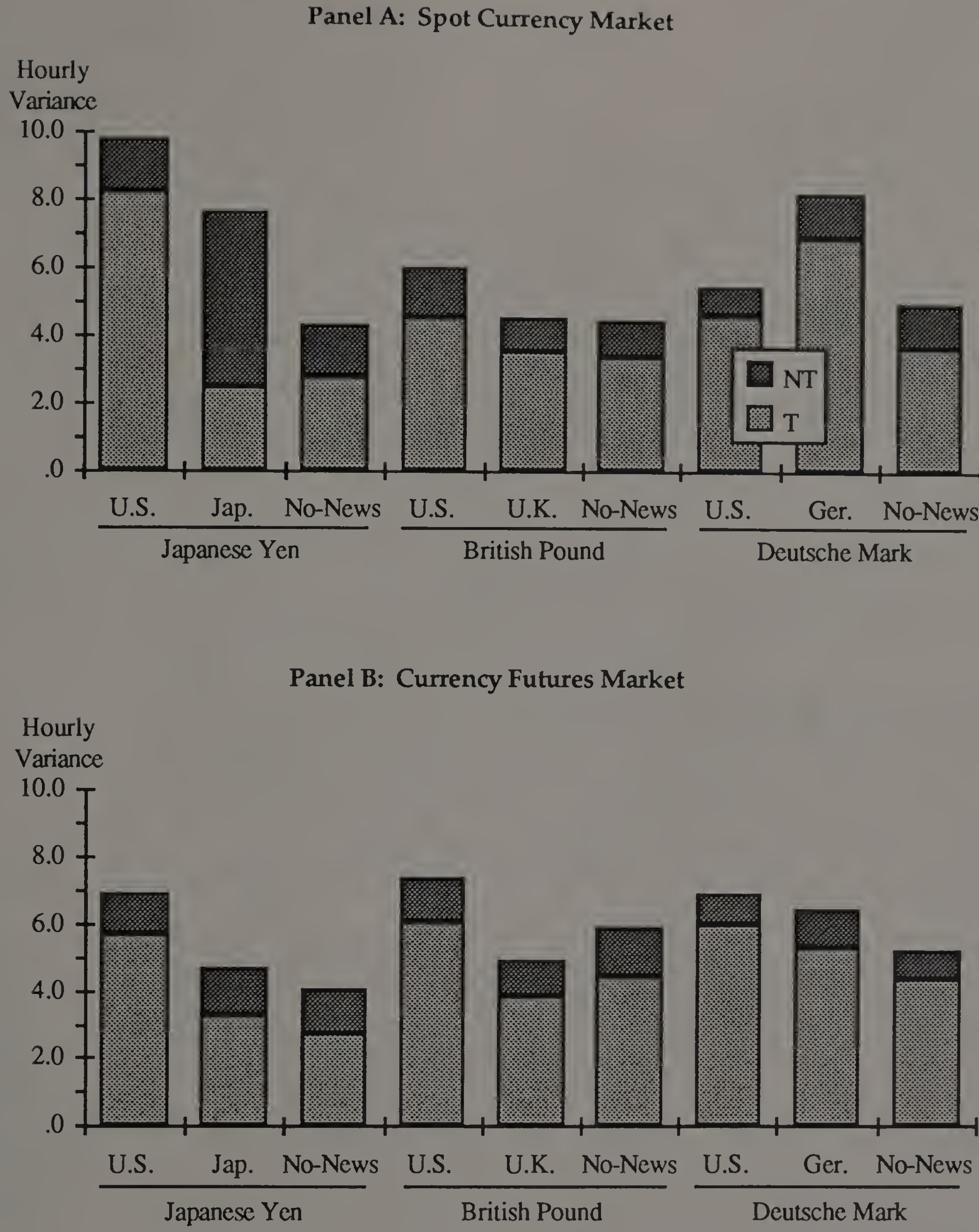

Figure 5.5: Volatility on U.S. and Foreign Announcement Dates

Shown are trading (T) and non-trading (NT) hourly variance rates on days of: (1) *U.S.* = U.S. release and no foreign release (for that country), (2) *Foreign* = foreign release (for that country — e.g., Ger.) and no U.S. release, and (3) *No-News* = no U.S. or foreign release (for that country). The hourly variances are scaled by 10^6 (e.g., 1,000,000). The sample period is January 4, 1988 to December 31, 1990 — except for the DM, which is from January 4, 1989 to December 31, 1990.

significantly greater than the afternoon variance for Tuesday and Friday — e.g., 3.470 and 3.175 Tuesday and Friday respectively for the yen, and also on Friday 3.071 for the pound and 2.134 for the mark. The significance for the yen on Thursday U.S. information release days is related to the release of money supply figures on Thursday afternoons (although after the trading period ends). To more closely examine information effects in the U.S. market structure, results in Table 5 also show the importance of macroeconomic news releases relative to days of no economic macroeconomic releases for the yen, pound, and mark. The ratio of the variance for morning sessions containing macroeconomic releases was significantly greater than morning sessions in which macroeconomic releases were absent. For mornings the average of the daily AM/AM variance ratio on days of information release to days of no information release was 5.46, 3.62, and 3.44 for the yen, pound, and mark respectively. The importance of Friday morning variance may reflect either information releases or market participants' closing position before the weekend. In contrast, PM/PM variance ratios for days of macroeconomic information release versus days in which no macroeconomic information is released, the ratios are similar. The averages of the daily PM/PM variance ratios on days of macroeconomic release to days of no macroeconomic release were 1.69, 1.14, and 1.36 for the yen, pound, and mark respectively.

5.2 Maximum Likelihood Results

In this section diffusion and jump-diffusion process models of exchange rate returns are used to examine the impact of macroeconomic news releases on trading or non-trading period variance. To minimize the problems associated with missing data in the spot market open/close data (e.g., the French and U.S. holidays do not always coincide, plus the French have more holidays than the U.S.) the maximum likelihood estimation of the four models are estimated only for trading and non-trading period currency futures returns.[19]

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[19] Estimating the diffusion and jump-diffusion process models only for currency futures returns seems justified since the results of Jorion's (1989) jump-process model over the 1974-85 period for the spot market were replicated using futures market data and resulted in essentially the sample parameter estimates.

In Section 5.2.1 an initial comparison of the four models is made, where models that have conditional variance (models II and IV) are conditioned on any of the four macroeconomic news announcements in this study. In Section 5.2.2, the four models are again compared. But, in this analysis, models II and IV are estimated separately for each of the four macroeconomic variables. Thus, this section provides evidence on the impact of specific news announcements on currency returns.

5.2.1 *Overall MLE Results*

In this section the results from estimating each of the four models of return generating process are presented for the mark, pound, and yen. The four models of the return generating process are as presented in Section 3.3. These models are summarized in Figure 4.1. A log-likelihood ratio test which can be used to compare nested models was detailed in Section 3.3.5. The hypotheses which can be tested are also shown graphically in Figure 4.1. Models I and III (diffusion and jump-diffusion processes, respectively) have no terms which are conditional on the release of news. Models II and IV, however, are the corresponding models with the addition of a variance term which is conditional on the release of news. In this first analysis, Models II and IV are estimated conditional on the release of any of the four macroeconomic variables in this study.

As can be seen from the Chi-square test statistics in Table 5.6, trading period returns follow a more complex process than a simple diffusion process. The simple diffusion process given by Model I is easily rejected in favor of any of the other three models for all three currencies. Specifically, Model II, which incorporates variance conditional on news, dominates a simple diffusion process. The jump-diffusion process given by Model III in turn dominates the simple diffusion process model. Model III, however, can only be rejected in favor of the conditional jump-diffusion process of Model IV at the 11% significance level for the mark and pound and the 5% level for the yen.

The results from estimating the four models for non-trading period returns are not as strong as those obtained for trading period returns. Model I is easily rejected in favor of both Models

III and IV for all three currencies. However, it can be rejected in favor of Model II only at the 13% level for the mark, the 5% level for the pound, and not at any reasonable level for the yen. In addition, Model III cannot be rejected in favor of Model IV at any reasonable level for any of the three currencies.

Overall, the Chi-square tests of the relative power of nested models of exchange rate returns indicate that macroeconomic news releases have a more significant impact on trading period returns than non-trading period returns. These results are consistent with the traditional variance ratio tests presented in Section 5.1. However, it is interesting to note that the parameters and log-likelihood values obtained from estimating the four models were nearly identical for the DM and BP for trading period returns, but not for non-trading period returns. There are two possible explanations for this result. First, there may be one dominant source of factors which cause currency movements when exchange rates are expressed relative to the U.S. dollar (e.g., U.S. macroeconomic announcements and other U.S. news). The second possible explanation is Britain's membership in the Exchange Rate Mechanism (ERM), which requires that the pound track the mark within a 2.5% bound.[20]

Correlation coefficients between the three currencies' returns are presented in Table 5.7. As can be seen in the table, on days of no macroeconomic news the correlations between the three currencies' trading period returns are relatively high — i.e. Corr(DM, BP) = .80, Corr(DM, JY) = .72, and Corr(BP, JY) = .72. However, the correlations between the same currencies on days of U.S. macroeconomic release range from .85 to .87. Thus, trading period returns are relatively highly correlated, but are even more highly correlated on days of U.S. news releases (especially in the case of the DM and BP).

Copeland (1989) states that he believes that between 5% and 20% of currency volatility can be explained by macroeconomic variables. If Copeland's assertion is correct, the unconditional variance parameter (σ_1^2) estimated in Model II should be between 5% and 20%

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[20] Although Britain did not join the ERM until 1990, efforts were made by the British central bank to "unofficially" keep the pound within the later formalized bound relative to the mark.

smaller than the same parameter estimated in Model I. As reported in Table 5.6, for DM trading period returns, $\sigma_1^2 = .275$ for Model I and $\sigma_1^2 = .225$ for Model II — which is 18% smaller. Similarly, the unconditional variance parameter for Model II is 18% smaller for the BP and 23% smaller for the JY trading period returns. Thus, between 18% and 23% of trading period variance can be explained collectively by the four macroeconomic factors which are the focus of this study. The remaining 77% to 82% is related to other factors — such as political events, etc. Foreign macroeconomic news, however, explains a smaller proportion of non-trading period total variance. The percentage explained by each country's own macroeconomic news releases are 4% for the DM and BP, but 0.0% for the JY.

5.2.2 *MLE Results for Individual Macroeconomic Releases*

An examination of the results of hypotheses tests for nested models of exchange rate returns for individual macroeconomic variables allows a formal analysis of the impact of each variable on the return generating process.[21] Table 5.8 reports the nested hypotheses test statistics for the four models when estimated for each macroeconomic variable separately — merchandise trade balance (MTB), industrial production (IP), money supply (MS), and consumer price index (CPI). (The parameter estimates for the models estimated and tested in Table 5.8 are given in Tables 5.9 and 5.10 for completeness.) For DM and BP trading-period returns, the simple diffusion process of Model I is rejected in favor of the conditional diffusion process of Model II at the 1% level for MTB and IP, but at the 11% level for MS. For the JY trading period returns, Model I is rejected in favor of Model II at the 1% level for all three of the same macro-variables. In contrast, for non-trading period returns Model I can be rejected in favor of Model II only for MTB for the DM and BP (1% and 2% levels, respectively) and MS for the BP (7% significance level). Model I cannot be rejected in favor of Model II for any of the four macrovariables at any level of significance for the JY.

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[21] Some macrovariables, however, are often released together. For the variables used here, this is only a problem for MTB and IP. About 40% of IP announcements are made on the same date as MTB.

As can be seen in Table 5.8, however, the conditional diffusion process of Model II, is rejected at the 1% level in favor of the conditional-variance jump-diffusion process of Model IV for both trading and non-trading period returns for all three currencies — and for all four macrovariables. It cannot be determined from this nested hypotheses test whether it is the jump-process or the conditional-variance process of Model IV which better explains the currency return process. However, Model III can only be rejected in favor of Model IV at between the 1% and 4% level (all three currencies) for MTB and IP for trading-period returns. For non-trading period returns only the JY has a variable which allows a rejection of Model III in favor of Model IV — i.e., IP at the 18% level. Thus, it appears that only for MTB and IP for trading period returns does the release of macroeconomic news explain the return generating process better than an unconditional jump-diffusion process.

Table 5.12 provides further evidence as to whether or not an unconditional jump-diffusion process dominates a conditional variance diffusion process by ranking nested and non-nested models according to the Schwarz Criterion. For trading period returns and MTB news releases, Model IV is ranked first and dominates all the other models for all three currencies. The unconditional jump-diffusion process of Model III, however, is ranked second only for the JY. For non-trading period returns, Model III dominates all other models for all three currencies — although Model IV with MTB releases is ranked second for the DM and BP and with IP releases for the JY. Thus, there is evidence that the release of macroeconomic news — especially MTB and IP — can provide understanding of the currency return generating process in addition to an unconditional diffusion or jump-diffusion process.

5.3 Summary

The trading/non-trading period variance ratio results presented in this chapter indicate that macroeconomic releases do on average have news content which increases volatility in both the spot and futures currency markets. For all three currencies, foreign macroeconomic news does not have as much impact on currency volatility as does equivalent U.S. macroeconomic news. However, of the three currencies, Japanese macro-variables have the smallest effect on volatilitiy In addition, the increase in volatility associated with a macro-release occurs in the period immediately surrounding the release. Finally, evidence is presented which indicates that public information is not always reflected in the futures market first. Instead, market liquidity differences and the timing of the announcement are factors that may in certain instances influence which market traders prefer and therefore will reflect public news first.

Diffusion and jump-diffusion process models of trading period exchange rate returns which contain a variance parameter conditional on the release of macroeconomic news are found to dominate equivalent models without a conditional variance parameter. When the results are broken down by type of macro-release, merchandise trade balance and industrial production are found to have the greatest impact. For non-trading period returns, the conditional variance diffusion process (but not the jump-diffusion process) model dominates the equivalent unconditional model only for merchandise trade balance (DM and BP) and money supply (BP). Overall, the release of the four U.S. macro-variables in this study U.S. can collectively explain about 20 percent of the total trading period currency volatility.

Table 5.1

Hourly Variance of Trading/Non-Trading Time Currency Returns
(January 4, 1988 – December 28, 1990)

Panel A: Spot Market Hourly Variances

	Japanese Yen		British Pound		Deutsche Mark	
	Non-trading	Trading	Non-trading	Trading	Non-trading	Trading
Monday	.0063	.0245	.0074	.0220	.0060	.0459
Tuesday	.0212	.0421	.0112	.0382	.0201	.0418
Wednesday	.0176	.0270	.0086	.0437	.0097	.0336
Thursday	.0177	.0878	.0153	.0427	.0092	.0438
Friday	.0327	.0414	.0136	.0468	.0081	.0479
Average	.0191	.0446	.0112	.0387	.0106	.0426

Panel B: Futures Market Hourly Variances

	Japanese Yen		British Pound		Deutsche Mark	
	Non-trading	Trading	Non-trading	Trading	Non-trading	Trading
Monday	.0060	.0170	.0075	.0354	.0055	.0275
Tuesday	.0153	.0327	.0184	.0501	.0113	.0456
Wednesday	.0168	.0278	.0133	.0338	.0106	.0358
Thursday	.0152	.0456	.0149	.0526	.0104	.0501
Friday	.0128	.0428	.0166	.0559	.0084	.0551
Average	.0165	.0332	.0183	.0456	.0123	.0428

Panel C: Trading to Non-Trading period Variance-Rate Ratios

	Japanese Yen		British Pound		Deutsche Mark	
	Spot	Futures	Spot	Futures	Spot	Futures
Monday	3.902*	2.821*	2.959*	4.740*	7.700*	4.968*
Tuesday	1.990*	2.143*	3.409*	2.726*	2.081*	4.038*
Wednesday	1.538	1.655	5.054*	2.536*	3.446*	3.388*
Thursday	4.973*	3.005*	2.800*	3.540*	4.755*	4.792*
Friday	1.269	3.354*	3.438*	3.371*	5.894*	6.546*
Average†	2.735	2.596	3.532	3.383	4.775	4.746

Panel D: Cash to Futures Variance-Rate Ratios

	Japanese Yen		British Pound		Deutsche Mark	
	Non-trading	Trading	Non-trading	Trading	Non-trading	Trading
Monday	1.045	1.445	.997	.623	1.079	1.672
Tuesday	1.388	1.289	.609	.762	1.779*	.917
Wednesday	1.045	.971	.648	1.291	.920	.936
Thursday	1.165	1.928*	1.026	.812	.882	.876
Friday	2.558*	.968	.820	.837	.965	.869
Average†	1.415	1.386	.807	.908	1.107	1.107

* Indicates significantly different from 1.00 at the 1% level.
† Statistical significance is not appropriate since an equally weighted average of daily variance ratios is reported.

Table 5.2

Release days of Monthly Macroeconomic Announcements

	Monday	Tuesday	Wednesday	Thursday	Friday	Percent Released Alone
			United States			
MTB	0	9	8	8	11	28.0%*
IP	1	9	10	3	13	50.0%*
CPI	0	13	9	6	8	67.0%
Percent of Total	0.9%	28.7%	25.0%	15.7%	29.6%	
			United Kingdom			
MTB	4	4	9	7	10	97.1%
IP	6	7	9	6	7	77.1%
MS	7	6	4	13	6	77.8%
CPI	0	0	0	2	34	66.7%
Percent of Total	12.1%	12.1%	15.6%	19.9%	40.4%	
			Japan			
MTB	13	3	4	5	11	63.9%
IP	8	9	7	6	4	61.8%
MS	10	11	0	1	13	91.4%
CPI	13	2	1	1	16	57.6%
Percent of Total	31.9%	18.1%	8.7%	9.4%	31.9%	
			Germany			
MTB	4	3	2	2	2	100.0%
IP	3	6	3	6	3	90.5%
MS	2	4	3	7	5	100.0%
CPI	3	1	7	6	3	95.0%
Percent of Total	16.0%	18.7%	20.0%	28.0%	17.3%	

"Percent of total" indicates the percentage of all monthly macroeconomic releases in this study which were made on that day of the week.
"Percent released alone" indicates for each macroeconomic variable the percentage which were not released on the same day as one or more of the other macrovariables in this study.
* The U.S. MTB and IP are often joint releases, thus the percentage released alone is very low for both. However, of the 36 MTB and IP releases, 15 (42%) are announced jointly.

Table 5.3

Variance-Rate Ratios: U.S. and Foreign Announcement Dates

Panel A: Yen

	No Info (T/NT)	# Obs	U.S. Info (T/NT)	# Obs	Jap. Info (NT/T)	#Obs
			Spot			
Monday	3.991*	101/102	--	--	.388	25/23
Tuesday	1.592*	111/94	2.016	16/16	.558	14/16
Wednesday	1.321	117/116	3.102*	23/23	.559	11/11
Thursday	--	--	4.849*	135/133	--	--
Friday	2.176*	96/95	30.652*	16/16	3.800*	30/30
All days	1.867*	425/407	5.209*	190/188	2.044*	80/80
			Futures			
Monday	3.084*	102	--	--	.253	22
Tuesday	2.365*	105	2.886	15	.432	14
Wednesday	1.624*	115	3.426*	21	.350	11
Thursday	--	--	3.003*	132	--	--
Friday	2.263*	94	48.408*	16	.570	29
All days	2.164*	416	4.354*	184	.448	76

Panel B: Pound

	No Info (T/NT)	# Obs	U.S. Info (T/NT)	# Obs	U.K. Info (NT/T)	#Obs
			Spot			
Monday	2.849*	107/110	--	--	.271	17/17
Tuesday	2.847*	114/99	7.147*	18/19	.355	9/13
Wednesday	4.856*	113/112	4.719*	17/17	.182	15/15
Thursday	--	--	2.654*	124/122	--	--
Friday	2.549*	102/101	-- ‡	3/3	.349	24/24
All days	3.167*	436/422	3.013	162/163	.281	65/69
			Futures			
Monday	5.197*	107	--	--	.140	17
Tuesday	2.305*	106	12.379*	17	.197	13
Wednesday	2.719*	111	4.766*	16	.477	15
Thursday	--	--	4.065*	121	--	--
Friday	2.810*	98	-- ‡	3	.314	25
All days	2.953*	422	4.576*	157	.277	70

\# *Obs* is the number of observations, given as (#Obs numerator)/(#Obs denominator) when they differ.

* Indicates significant at the 1% level. (Significance is only reported for the cases where the ratio is greater than 1.00, since that is the direction of interest.

‡ Results for these cases are not reliable since there are only three observations. Consequently they are not reported.

Table 5.3 Continued

Panel C: Deutsche Mark‡

	No Info (T/NT)	# Obs	U.S. Info (T/NT)	# Obs	Ger. Info (NT/T)	#Obs
			Spot			
Monday	4.963*	74/74	--	--	.066	12/12
Tuesday	1.581	73/63	4.045*	13/14	.361	9/7
Wednesday	2.723*	72/70	8.413*	14/14	.130	13/13
Thursday	--	--	5.591*	83/82	--	--
Friday	5.115*	74/75	16.591*	13/13	.641	14/14
All days	2.797*	293/282	5.659*	123/123	.187	48/46
			Futures			
Monday	5.716*	74	--	--	.139	12
Tuesday	4.840*	69	5.904*	14	.291	10
Wednesday	3.566*	70	13.420*	14	.113	14
Thursday	--	--	5.892*	84	--	--
Friday	5.969*	74	27.405*	13	.396	12
All days	4.920*	287	6.689*	125	.218	48

Obs is the number of observations, given as (#Obs numerator)/(#Obs denominator) when they differ.
* Indicates significant at the 1% level. (Significance is only reported for the cases where the ratio is greater than 1.00, since that is the direction of interest.
‡ The period used for the Deutsche mark was 1/4/89 to 12/28/90.

Table 5.4

Ratio of U.S. Information Day Trading Period Hourly Variance to Foreign Information Day Non-Trading Period Hourly Variance

Panel A: Spot Currency Market Hourly Variance Ratios

	Japanese Yen		British Pound		Deutsche mark ‡	
	Var. Ratio (T/NT)	# Obs	Var. Ratio (T/NT)	# Obs	Var. Ratio (T/NT)	# Obs
Monday	--	--	--	--	--	--
Tuesday	1.750	16/14	4.348	18/9	6.764*	13/7
Wednesday	1.399	23/11	2.644	17/15	5.294*	14/13
Thursday	--	--	--	--	--	--
Friday	1.385	16/30	--†	3/24	1.202	13/14

Panel B: Futures Market Hourly Variance Ratios

	Japanese Yen		British Pound		Deutsche mark ‡	
	Var. Ratio (T/NT)	# Obs	Var. Ratio (T/NT)	# Obs	Var. Ratio (T/NT)	# Obs
Monday	--	--	--	--	--	--
Tuesday	1.523	15/14	4.422*	17/13	5.814*	14/10
Wednesday	1.611	21/11	1.204	16/15	7.040*	14/14
Thursday	--	--	--	--	--	--
Friday	9.354*	16/29	--†	3/25	2.013	13/12

Obs is the number of observations, given as (#Obs numerator)/(#Obs denominator).

* Indicates significantly different from 1.00 at the 1% level.

† The variance ratio is not reported, since there were only three trading period returns to calculate the variance from.

‡ The period used for the Deutsche mark was 1/4/89 to 12/28/90.

Table 5.5

Variance Ratios for U.S. Spot Market Trading Time Morning and Afternoon Sub-Periods

	Variance Ratio for AM/PM Trading Sub Periods on U.S. Release Days		Variance Ratio for AM/PM Trading Sub Periods on Days of No U.S. Release		Variance Ratio of U.S. to No U.S. Releases for AM and PM Sub Periods	
	Ratio	# Obs	Ratio	# Obs	AM	PM
Panel A: Yen						
Monday	--	--	.593*	128/135	--	--
Tuesday	3.470*	23/22	.509*	127/131	6.779*	.994
Wednesday	.324*	23/24	.413*	129/129	1.483	1.893*
Thursday	.260*	148/153	--	--	--	--
Friday	3.175*	21/23	.857	128/128	8.119*	2.191*
Average†	1.807		.593		5.460	1.693
Panel B: Pound						
Monday	--	--	.669	128/135	--	--
Tuesday	.981	23/22	.541*	127/131	2.784*	1.536
Wednesday	.410	23/24	.258*	129/129	1.154	.725
Thursday	.417	148/153	--	--	--	--
Friday	3.071*	21/23	.518*	128/128	6.924*	1.167
Average†	1.220		.496		3.620	1.142
Panel C: Deutsche Mark						
Monday	--	--	.234*	128/135	--	--
Tuesday	1.099	23/22	.459*	127/131	2.635*	1.099
Wednesday	.641	23/24	.451*	129/129	1.791	1.261
Thursday	.613	148/153	--	--	--	--
Friday	2.134	21/23	.625*	128/128	5.920*	1.733*
Average†	1.122		.442		3.449	1.364

Obs is the number of observations, given as (#Obs numerator)/(#Obs denominator).

* Indicates significantly different from 1.00 at the 1% level.

† Statistical significance is not appropriate since an equally weighted average of daily variance ratios is reported.

Table 5.6

Maximum Likelihood Estimation of Diffusion and Jump-Diffusion Process Models

Model	μ	σ_1^2	σ_2^2	λ	θ	δ^2	log likelihood	χ^2 test against I	χ^2 test against II	χ^2 test against III
Panel A: Trading Period Returns (Deutsche Mark Futures)										
I	.023 (1.21)	.275* (30.72)					-586.06			
II	.021 (1.11)	.225* (20.21)	.168* (6.87)				-572.64	26.84*(a) [.000]		
III	.021 (.93)	.085 (.42)		.639* (2.97)	.004 (.10)	.295* (3.70)	-548.44	75.24*(b) [.000]		
IV	.016 (.77)	.077* (3.69)	.043 (1.56)	.658* (2.83)	.007 (.19)	.277* (3.52)	-547.17	77.78*(c) [.000]	50.94*(b) [.000]	2.54(a) [.111]
Panel B: Non-Trading Period Returns (Deutsche Mark Futures)										
I	-.013 (-.63)	.213* (25.82)					-338.80			
II	-.013 (-.61)	.204* (23.25)	.062 (2.14)				-337.66	2.28(a) [.131]		
III	-.065* (-2.82)	.060* (3.55)		.657* (2.76)	.079 (1.77)	.221* (3.51)	-306.18	65.24*(b) [.000]		
IV	-.065* (-2.83)	.060* (3.48)	.000 (.00)	.655* (2.76)	.079 (1.78)	.222* (3.48)	-306.18	65.24*(c) [.000]	62.96*(b) [.000]	.00(a) [1.000]

Critical values at the 1% and 5% levels are, respectively: (a) 6.63, 3.84; (b) 11.34, 7.81; (c) 13.28, 9.49. * denotes significant at the 1% level. Number of observations for the Deutsche mark are 526 for both trading and non-trading period returns.

Table 5.6 Continued

Model	μ	σ_1^2	σ_2^2	λ	θ	δ^2	log likelihood	χ^2 test against I	χ^2 test against II	χ^2 test against III
Panel C: Trading Period Returns (British Pound Futures)										
I	.023	.274*					-586.06			
	(1.22)	(30.84)								
II	.020	.225*	.172*				-572.64	26.85*(a)		
	(1.11)	(20.21)	(6.91)					[.000]		
III	.020	.085*		.640*	.004	.295*	-548.44	75.24*(b)		
	(.93)	(4.21)		(2.97)	(.10)	(3.69)		[.000]		
IV	.018	.076*	.043	.660*	.007	.276*	-547.17	77.78*(c)	50.94*(b)	2.54*(c)
	(.78)	(3.68)	(1.55)	(2.82)	(.18)	(3.52)		[.000]	[.000]	[.111]
Panel D: Non-Trading Period Returns (British Pound Futures)										
I	-.027	.197*					-461.46			
	(-1.68)	(31.23)								
II	-.027	.190*	.061*				-459.54	3.84(a)		
	(-1.67)	(58.22)	(5.29)					[.050]		
III	-.051*	.050*		.725*	.033	.199*	-415.44	92.04*(b)		
	(-2.83)	(4.09)		(3.53)	(1.12)	(4.34)		[.000]		
IV	-.052*	.051*	.000	.721*	.033	.200*	-415.44	92.04*(c)	88.20*(b)	.00(a)
	(-2.86)	(4.03)	(.00)	(3.51)	(1.11)	(4.31)		[.000]	[.000]	[1.000]

Critical values at the 1% and 5% levels are, respectively: (a) 6.63, 3.84; (b) 11.34, 7.81; (c) 13.28, 9.49. * denotes significant at the 1% level. Number of observations for the British pound are 758 for both trading and non-trading period returns.

Table 5.6 Continued

Model	μ	σ_1^2	σ_2^2	λ	θ	δ^2	log likelihood	χ^2 test against I	χ^2 test against II	χ^2 test against III
Panel E: Trading Period Returns (Japanese Yen Futures)										
I	.001	.214*					-493.75			
	(.05)	(44.92)								
II	.001	.165*	.174*				-472.12	43.26*(a)		
	(.09)	(25.76)	(11.79)					[.000]		
III	.006	.073*		.326*	-.017	.407*	-408.82	169.86*(b)		
	(.42)	(7.93)		(4.29)	(-.34)	(5.42)		[.000]		
IV	.008	.071*	.037	.277*	-.024	.447*	-406.93	173.64*(c)	130.38*(b)	3.78(a)
	(.51)	(7.73)	(2.09)	(4.04)	(-.41)	(5.13)		[.000]	[.000]	[.052]
Panel F: Non-Trading Period Returns (Japanese Yen Futures)										
I	-.029	.284*					-599.476			
	(-1.51)	(30.44)								
II	-.029	.284*	.004				-599.472	.01(a)		
	(-1.49)	(28.73)	(.13)					[.920]		
III	-.047	.037*		1.144*	.015	.211*	-549.797	99.36*(b)		
	(-2.24)	(3.08)		(4.85)	(.67)	(5.53)		[.000]		
IV	-.045	.026*	.023	1.290*	.013	.191*	-549.189	100.57*(c)	100.57*(b)	1.22(a)
	(-2.22)	(2.82)	(.78)	(5.42)	(.65)	(6.02)		[.000]	[.000]	

Critical values at the 1% and 5% levels are, respectively: (a) 6.63, 3.84; (b) 11.34, 7.81; (c) 13.28, 9.49. * denotes significant at the 1% level. Number of observations for the Japanese yen are 758 for both the trading and non-trading period returns.

Table 5.7

Correlations Between Currency Returns

	Trading Period						NT
	No U.S. Macro News	U.S. Macro News	MTB	IP	MS	CPI	All Days
(DM, BP)	.80	.87	.96	.94	.83	.87	.75
(DM, JY)	.72	.85	.93	.94	.81	.85	.66
(BP, JY)	.72	.86	.96	.95	.82	.75	.59
Obs.	534	224	36	36	153	38	758

Table 5.8

Summary of Chi-Square Tests of Conditional-Information Models by Type of Macroeconomic Information Release

Panel A: Deutsche Mark

Model	Type of Info Release	χ^2 Test Against Model I		χ^2 Test Against Model II		χ^2 Test Against Model III	
		Trading	Non-Trading	Trading	Non-Trading	Trading	Non-Trading
II	MTB	73.79 [.00]	4.57 [.03]				
	IP	30.17 [.00]	.54 [.46]				
	MS	2.50 [.11]	2.63 [.10]				
	CPI	.03 [.86]	.01 [.92]				
III	--	75.24* [.00]	65.24* [.00]				
IV	MTB	118.40* [.00]	65.24* [.00]	44.62* [.00]	60.66* [.00]	43.16* [.00]	.00 [1.00]
	IP	80.55* [.00]	65.24* [.00]	50.38* [.00]	64.70* [.00]	5.31 [.02]	.00 [1.00]
	MS	75.98* [.00]	65.24* [.00]	73.48 [.00]	62.70* [.00]	.74 [.39]	.00 [1.00]
	CPI	75.40* [.00]	65.24* [.00]	75.36 [.00]	65.22* [.00]	.16 [.69]	.00 [1.00]

Notes:
* indicates significant at the 1% level. P-values are given underneath the test statistics in brackets. The Chi-square tests of Model IV versus Model II are matched in terms of type of information release (e.g., MTB Model IV versus MTB Model II, and so on). No matching is necessary for Models I and III since they do not condition on information.

Abbreviations for macroeconomic information releases used are:
MTB = merchandise trade balance,
IP = industrial production,
MS = money supply,
CPI = consumer price index.

Table 5.8 Continued

Panel B: British Pound

Model	Type of Info Release	χ^2 Test Against Model I		χ^2 Test Against Model II		χ^2 Test Against Model III	
		Trading	Non-Trading	Trading	Non-Trading	Trading	Non-Trading
II	MTB	73.79 [.00]	5.48 [.02]				
	IP	30.17 [.00]	.90 [.34]				
	MS	2.51 [.11]	3.39 [.07]				
	CPI	.04 [.84]	.03 [.86]				
III	CPI	75.24* [.00]	92.04* [.00]				
IV	MTB	118.40* [.00]	92.04* [.00]	44.62* [.00]	86.56* [.00]	43.16* [.00]	.00 [1.00]
	IP	80.54* [.00]	92.04* [.00]	50.38* [.00]	86.56* [.00]	5.31 [.02]	.00 [1.00]
	MS	75.98* [.00]	92.04* [.00]	73.48 [.00]	86.56* [.00]	.74 [.39]	.00 [1.00]
	CPI	75.40* [.00]	92.04* [.00]	75.36 [.00]	86.56* [.00]	.16 [.69]	.00 [1.00]

Table 5.8 Continued

Panel C: Japanese Yen

Model	Type of Info Release	χ^2 Test Against Model I		χ^2 Test Against Model II		χ^2 Test Against Model III	
		Trading	Non-Trading	Trading	Non-Trading	Trading	Non-Trading
II	MTB	103.01* [.00]	.01 [.92]				
	IP	58.85* [.00]	.002 [.96]				
	MS	9.77* [.00]	.17 [.68]				
	CPI	.00 [1.00]	.002 [.96]				
III	--	169.86* [.00]	99.36* [.00]				
IV	MTB	200.16* [.00]	99.59* [.00]	97.14* [.00]	99.89* [.00]	30.30* [.00]	.54 [.46]
	IP	174.12* [.00]	101.19* [.00]	115.26* [.00]	101.19* [.00]	4.26 [.04]	1.84 [.18]
	MS	170.96* [.00]	99.43* [.00]	161.18* [.00]	99.26* [.00]	1.10 [.30]	.08 [.78]
	CPI	169.86* [.00]	99.37* [.00]	169.86* [.00]	99.37* [.00]	.00 [1.00]	.02 [.89]

Table 5.9

Chi-Square Tests of Model II Versus Model I
Broken Down by Type of Macroeconomic Information Release
Deutsche Mark

Type of Macro-Release	μ	σ_1^2	σ_2^2	Log Likelihood	χ^2 test against I
Panel A: Trading Period Returns & U.S. Information					
Model I:	.023	.275*		-586.06	
	(1.22)	(30.72)			
Model II:					
All 4 Info Types	.020	.225*	.168*	-572.64	26.84*
	(1.11)	(20.21)	(6.91)		[.000]
Merchandise Trade Balance	.024	.231*	.925*	-549.17	73.79*
	(1.32)	(24.12)	(4.00)		[.000]
Industrial Production	.022	.251*	.508*	-570.98	30.17*
	(1.19)	(24.29)	(4.97)		[.000]
Money Supply	.022	.263*	.057	-584.81	2.50
	(1.13)	(28.04)	(2.01)		[.114]
CPI	.023	.274*	.013	-586.04	.03
	(1.20)	(30.36)	(0.21)		[.862]
Panel B: Non-Trading Period Returns & German Information					
Model I:	-.013	.213*		-338.80	
	(.63)	(25.82)			
Model II:					
All 4 Types	-.013	.204*	.062	-337.66	2.28
	(-.62)	(23.25)	(2.14)		[.131]
Merchandise Trade Balance	-.012	.206*	.221	-336.51	4.57
	(-.57)	(25.28)	(1.87)		[.033]
Industrial Production	-.013	.210*	.058	-338.53	.54
	(-.63)	(25.09)	(1.16)		[.462]
Money Supply	-.012	.206*	.131	-337.48	2.63
	(-.57)	(24.87)	(2.03)		[.105]
CPI	-.013	.212*	.000	-338.79	.01
	(-.65)	(25.83)	(.00)		[.920]

T-test critical values at the 1% and 5% level are 2.58 and 1.96, respectively. Chi-square critical values at the 1% and 5% levels are 6.63 and 3.84, respectively. * indicates significant at the 1% level. T-values are reported underneath parameter estimates in parentheses, while P-values for chi-square tests are reported underneath the test statistics in brackets.

Table 5.9 Continued

British Pound

Type of Macro-Release	μ	σ_1^2	σ_2^2	Log Likelihood	χ^2 test against I
Panel C: Trading Period Returns & U.S. Information					
Model I:	.023	.274*		-586.06	
	(1.22)	(30.84)			
Model II:					
All 4 Info Types	.020	.225*	.172*	-572.64	26.85*
	(1.11)	(20.21)	(6.91)		[.000]
Merchandise Trade Balance	.024	.231*	.924*	-549.17	73.79*
	(1.32)	(24.12)	(4.00)		[.000]
Industrial Production	.022	.251*	.508*	-570.98	30.17*
	(1.13)	(24.29)	(4.99)		[.000]
Money Supply	.022	.263*	.059	-584.81	2.51
	(1.13)	(28.04)	(2.01)		[.113]
CPI	.023	.274*	.013	-586.04	.04
	(1.20)	(30.36)	(.21)		[.841]
Panel D: Non-Trading Period Returns & UK Information					
Model I:	-.027	.197*		-461.46	
	(-1.68)	(31.23)			
Model II:					
All 4 Types	-.027	.190*	.061*	-459.54	3.84
	(-1.67)	(58.22)	(5.29)		[.050]
Merchandise Trade Balance	-.026	.194*	.228	-458.72	5.48
	(-1.60)	(30.60)	(1.95)		[.019]
Industrial Production	-.027	.196*	.071	-461.01	.90
	(-1.65)	(30.46)	(1.42)		[.343]
Money Supply	-.026	.194*	.142	-459.76	3.39
	(-1.60)	(30.25)	(2.20)		[.066]
CPI	-.027	.197*	.011	-461.45	.03
	(-1.68)	(31.02)	(.21)		[.862]

T-test critical values at the 1% and 5% level are 2.58 and 1.96, respectively. Chi-square critical values at the 1% and 5% levels are 6.63 and 3.84, respectively. * indicates significant at the 1% level. T-values are reported underneath parameter estimates in parentheses, while P-values for chi-square tests are reported underneath the test statistics in brackets.

Table 5.9 Continued

Japanese Yen

Type of Macro-Release	μ	$\sigma_1{}^2$	$\sigma_2{}^2$	Log Likelihood	χ^2 test against I
		Panel E: Trading Period Returns & U.S. Information			
Model I:	.0007	.214*		-493.75	
	(.05)	(44.92)			
Model II:					
All 4 Types	.001	.165*	.174*	-472.12	43.26*
	(.09)	(25.76)	(11.79)		[.000]
Merchandise Trade Balance	.003	.172*	.890*	-442.24	103.01*
	(.22)	(30.56)	(6.05)		[.000]
Industrial Production	.002	.185*	.616*	-464.32	58.85*
	(.12)	(31.20)	(7.22)		[.000]
Money Supply	-.0004	.196*	.093*	-488.86	9.77*
	(-.03)	(39.50)	(5.49)		[.000]
CPI	.0008	2.14*	.000	-493.75	.00
	(.05)	(44.99)	(.00)		[1.000]
		Panel F: Non-Trading Period Returns & Japanese Information			
Model I:	-.029	.284*		-599.476	
	(-1.51)	(30.44)			
Model II:					
All 4 Types	-.029	.284*	.004	-599.472	.01
	(-1.49)	(28.73)	(.13)		[.920]
Merchandise Trade Balance	-.029	.284*	.005	-599.473	.01
	(-1.50)	(30.16)	(.07)		[.920]
Industrial Production	-.029	.284*	.000	-599.475	.002
	(1.51)	(30.20)	(.00)		[.964]
Money Supply	-.031	.284*	.032	-599.389	.17
	(-1.56)	(29.33)	(.721)		[.680]
CPI	-.029	.285*	.000	-599.475	.002
	(-1.51)	(30.20)	(.00)		[.964]

T-test critical values at the 1% and 5% level are 2.58 and 1.96, respectively. Chi-square critical values at the 1% and 5% levels are 6.63 and 3.84, respectively. * indicates significant at the 1% level. T-values are reported underneath parameter estimates in parentheses, while P-values for chi-square tests are reported underneath the test statistics in brackets.

Table 5.10

Chi-Square Tests of Model III Versus Model IV
Broken Down by Type of Macroeconomic Information Release
Deutsche Mark

Type of Macro-Release	μ	σ_1^2	σ_2^2	λ	θ	δ^2	Log Likelihood	χ^2 test against III
Panel A: Trading Period								
Model III:	.021	.085*		.639*	.004	.295*	-548.44	
	(.93)	(4.21)		(2.97)	(.10)	(3.70)		
Model IV:								
All 4	.016	.077*	.043	.658*	.007	.277*	-547.17	2.54
	(.77)	(3.69)	(1.56)	(2.83)	(.19)	(3.52)		[.111]
MTB	.014	.083*	.901*	.647	.015	.233	-526.86	43.16*
	(.58)	(3.40)	(3.69)	(2.02)	(.38)	(2.51)		[.000]
IP	.017	.087*	.312*	.629	.006	.273*	-545.79	5.31
	(.75)	(3.77)	(2.58)	(2.38)	(.15)	(2.86)		[.021]
MS	.020	.081*	.022	.799*	.005	.294*	-548.07	.74
	(.90)	(4.00)	(.79)	(2.96)	(.13)	(3.67)		[.390]
CPI	.020	.084*	.018	.642*	.005	.294*	-548.36	.16
	(.88)	(4.19)	(.33)	(2.98)	(.13)	(3.71)		[.689]
Panel B: Non-Trading Period								
Model III:	-.065*	.060*		.657*	.079	.221*	-306.18	
	(-2.82)	(3.55)		(2.76)	(1.77)	(3.51)		
Model IV:								
All 4	-.065*	.060*	.000	.655*	.079	.222*	-306.18	.00
	(-2.83)	(3.48)	(.00)	(2.76)	(1.78)	(3.48)		[1.000]
MTB	-.066*	.060*	.000	.649*	.080	.225*	-306.18	.00
	(-2.84)	(3.57)	(.00)	(2.74)	(1.76)	(3.46)		[1.000]
IP	-.064*	.059*	.000	.661*	.077	.220*	-306.18	.00
	(-2.80)	(3.49)	(.00)	(2.75)	(1.77)	(3.49)		[1.000]
MS	-.065*	.060*	.000	.657*	.079	.221*	-306.18	.00
	(-2.83)	(3.53)	(.00)	(2.75)	(1.78)	(3.49)		[1.000]
CPI	-.065*	.060*	.000	.655*	.079	.222*	-306.18	.00
	(-2.83)	(3.54)	(.00)	(2.76)	(1.77)	(3.50)		[1.000]

T-test critical values at the 1% and 5% level are 2.58 and 1.96, respectively. Chi-square critical values at the 1% and 5% levels are 6.63 and 3.84, respectively. * indicates significant at the 1% level. T-values are reported underneath parameter estimates in parentheses, while P-values for chi-square tests are reported underneath the test statistics in brackets.

Table 5.10 Continued

British Pound

Type of Macro-Release	μ	σ_1^2	σ_2^2	λ	θ	δ^2	Log Likelihood	χ^2 test against III
				Panel C: Trading Period				
Model III:	.020	.085*		.640*	.004	.295*	-548.44	
	(.93)	(4.21)		(2.97)	(.10)	(3.69)		
Model IV:								
All 4	.018	.076*	.043	.660*	.007	.276*	-547.17	2.54
	(.78)	(3.68)	(1.55)	(2.82)	(.18)	(3.52)		[.111]
MTB	.013	.083*	.902*	.647	.015	.234	-526.86	43.16*
	(.58)	(3.40)	(3.69)	(2.20)	(.38)	(2.51)		[.000]
IP	.017	.087*	.312*	.627	.006	.274*	-545.79	5.31
	(.75)	(3.78)	(2.58)	(2.38)	(.15)	(2.86)		[.021]
MS	.020	.081*	.022	.643*	.005	.291*	-548.07	.74
	(.91)	(3.98)	(.79)	(2.96)	(.12)	(3.68)		[.390]
CPI	.019	.084*	.018	.641*	.005	.294*	-548.36	.16
	(.88)	(4.19)	(.33)	(2.98)	(.13)	(3.71)		[.689]
				Panel D: Non-Trading Period				
Model III:	-.051*	.050*		.725*	.033	.199*	-415.44	
	(-2.83)	(4.09)		(3.53)	(1.12)	(4.34)		
Model IV:								
All 4	-.052*	.051*	.000	.721*	.033	.200*	-415.44	.00
	(-2.86)	(4.03)	(.00)	(3.51)	(1.11)	(4.31)		[1.000]
MTB	-.051*	.050*	.000	.722*	.033	.200*	-415.44	.00
	(-2.82)	(4.10)	(.00)	(3.53)	(1.11)	(4.32)		[1.000]
IP	-.051*	.050*	.000	.724*	.033	.200*	-415.44	.00
	(-2.82)	(4.06)	(.00)	(3.53)	(1.11)	(4.33)		[1.000]
MS	-.051*	.050*	.000	.724*	.033	.199*	-415.44	.00
	(-2.82)	(4.07)	(.00)	(3.53)	(1.11)	(4.33)		[1.000]
CPI	-.051*	.050*	.000	.724*	.033	.200*	-415.44	.00
	(-2.82)	(4.07)	(.00)	(3.53)	(1.11)	(4.33)		[1.000]

T-test critical values at the 1% and 5% level are 2.58 and 1.96, respectively. Chi-square critical values at the 1% and 5% levels are 6.63 and 3.84, respectively. * indicates significant at the 1% level. T-values are reported underneath parameter estimates in parentheses, while P-values for chi-square tests are reported underneath the test statistics in brackets.

Table 5.10 Continued

Japanese Yen

Type of Macro-Release	μ	σ_1^2	σ_2^2	λ	θ	δ^2	Log Likelihood	χ^2 test against III
				Panel E: Trading Period				
Model III:	.006	.073*		.326*	-.017	.407*	-408.82	
	(.42)	(7.93)		(4.29)	(-.34)	(5.42)		
Model IV:								
All 4	.008	.071*	.037	.277*	-.024	.447*	-406.93	3.78
	(.51)	(7.73)	(2.09)	(4.04)	(-.41)	(5.13)		[.052]
MTB	.006	.065*	.810*	.379*	-.007	.286*	-393.67	30.30*
	(.36)	(6.30)	(5.11)	(3.24)	(.15)	(3.80)		[.000]
IP	.005	.072*	.123	.309*	-.013	.411*	-406.69	4.26
	(.32)	(7.89)	(1.79)	(4.11)	(-.25)	(4.87)		[.039]
MS	.008	.071*	.019	.316*	-.021	.415*	-408.27	1.10
	(.52)	(7.62)	(1.04)	(4.25)	(-.41)	(5.37)		[.294]
CPI	.005	.072*	.004	.342*	-.012	.386*	-408.82	.00
	(.34)	(7.56)	(.00)	(4.21)	(-.25)	(5.44)		[1.000]
				Panel F: Non-Trading Period				
Model III:	-.047	.037*		1.144*	.015	.211*	-549.797	
	(-2.24)	(3.08)		(4.85)	(.67)	(5.53)		
Model IV:								
All 4	-.045	.026*	.023	1.290*	.013	.191*	-549.189	1.22
	(-2.22)	(2.82)	(.78)	(5.42)	(.65)	(6.02)		[.269]
MTB	-.048	.034*	.030	1.178*	.016	.205*	-549.53	.54
	(-2.29)	(3.01)	(.52)	(4.95)	(.72)	(5.63)		[.462]
IP	-.045	.033*	.061	1.164*	.015	.207*	-548.88	1.84
	(-2.21)	(3.07)	(.82)	(5.06)	(.68)	(5.72)		[.175]
MS	-.047	.036*	.008	1.155*	.016	.209*	-549.76	.08
	(-2.26)	(3.05)	(.21)	(4.88)	(.70)	(5.56)		[.777]
CPI	-.047	.037*	.003	1.142*	.016	.211	-549.79	.02
	(-2.25)	(3.07)	(.03)	(4.83)	(.69)	(5.51)		[.888]

T-test critical values at the 1% and 5% level are 2.58 and 1.96, respectively. Chi-square critical values at the 1% and 5% levels are 6.63 and 3.84, respectively. * indicates significant at the 1% level. T-values are reported underneath parameter estimates in parentheses, while P-values for chi-square tests are reported underneath the test statistics in brackets.

Table 5.11

Summary of Schwarz Criterion Ranking of Models

Model	Type of Info Release	Deutsche Mark		British Pound		Japanese Yen	
		Trading	Non-Trading	Trading	Non-Trading	Trading	Non-Trading
I	- -	-572.7	-345.1 (3)	-592.7	-468.1 (3)	-500.4	-606.1
II	MTB	-559.1 (2)	-347.1	-559.1 (2)	-468.7 (4)	-432.2	-609.4
	IP	-580.9	-345.9 (4)	-580.9	-471.0	-474.3	-609.4
	MS	-594.8	-346.9	-594.8	-469.7	-498.8	-609.3
	CPI	-596.0	-348.2	-596.0	-471.4	-503.7	-609.4
III	- -	-565.0 (3)	-321.8 (1)	-565.0 (3)	-432.0 (1)	-425.4 (2)	-566.4 (1)
IV	MTB	-546.8 (1)	-325.0 (2)	-546.8 (1)	-435.3 (2)	-413.6 (1)	-569.4 (3)
	IP	-565.7 (4)	-325.0 (2)	-565.7 (4)	-435.3 (2)	-426.6 (3)	-568.8 (2)
	MS	-568.0	-325.0 (2)	-568.0	-435.3 (2)	-428.2 (4)	-569.7 (4)
	CPI	-568.3	-325.0 (2)	-568.3	-435.3 (2)	-428.7	-569.7 (4)

The Schwarz Criterion adjusts the log-likelihood value for the number of parameters in the model according to the equation $SC = lnL(\gamma; x) - .5*k*ln(T)$. Thus, models with more parameters are penalized. The best four models have their ranks given in parentheses after the Schwarz Criterion.

CHAPTER 6

CONCLUSIONS

In this study the pattern of inter- and intraday return variances for both spot exchange rates and currency futures prices for the Japanese yen, British pound, and Deutsche mark over the 1988-90 period is examined. Daily returns are partitioned into the traditionally used trading period returns (U.S. cash and futures markets are open) and non-trading period returns (U.S. cash and futures markets are closed, but foreign markets may be open). The impact of specific U.S. macroeconomic releases and the corresponding foreign macroeconomic releases on spot and futures return variance for each of the three currencies are examined. The results indicate that for all three currencies studied, spot and futures exchange rate return variances differ between U.S. trading and non-trading period. The results obtained for the Japanese yen are in agreement with the work by other authors which indicates that Japanese macroeconomic information releases have a positive impact on currency variance during foreign trading periods (U.S. non-trading time) which is similar to, but smaller than, the increase in U.S. trading period variance that occurs on U.S. macroeconomic release dates. However, while the results for the British pound and the Deutsche mark indicate an increase in foreign trading period variance on days of U.K. and German macroeconomic releases similar to that for the Japanese yen, the increase in variance for both currencies is smaller than for the yen. Finally, after partitioning the U.S. trading time into morning and afternoon sub-periods, the variance impact of U.S. macroeconomic information releases takes place in the period immediately surrounding the information release.

In this study diffusion and jump-diffusion process models which contain an additional variance parameter conditional on the release of macroeconomic news are developed. The parameters in these models are estimated using the method of maximum likelihood. Likelihood ratio tests for trading-period returns indicate that conditional variance diffusion and jump-diffusion process models dominate the equivalent non-conditional models when merchandise trade balance or industrial production figures are released by the U.S. government. For non-trading period returns, the conditional variance diffusion process (but not jump-diffusion process) model dominates the equivalent unconditional model only for merchandise trade balance (DM and BP) and money supply (BP). Thus, the results of this study provide compelling evidence that the currency return generating process is not characterized by a simple diffusion process over intraday periods. Further, the release of U.S. and foreign macroeconomic news has been shown to provide additional understanding of the return process over and above more complex models such as a jump-diffusion process. Finally, this paper has shown that on days of the release of a U.S. macrovariable, approximately 20 percent of the total trading period currency volatility can be explained by that news event.

Results from this analysis have implications for various trading strategies and studies of economics of information. If return variance is nonstationary between trading days, then models based on this risk measure must likewise adjust for the nonstationarity of variance. Thus results have significance for the importance of GLOBEX as an international trading system. In addition, further tests must be conducted on the relative importance of information released. The significance of particular macroeconomic information releases may well be country dependent. Future research is required to determine the relative impact of the macroeconomic and microeconomic information impacts in various markets and the degree to which the globalization of markets results in similar information reactions across countries.

APPENDIX A

DESCRIPTIVE STATISTICS

In this appendix some basic descriptive statistics for currency futures trading and non-trading period returns are presented. In Figure A.1, histograms are plotted for the return distributions for each of the currency futures contracts studied. From even a casual visual inspection of the distributions it can seen that over the period studied all the distributions have a very pointed shape. Only the distributions of the non-trading period returns for the Japanese yen and trading period returns for the Deutsche mark appear to have fat enough tails to have been drawn from a population which has a normal distribution. Descriptive statistics for each of the currencies are presented in Table A.1. Again, only these two distributions have a Wald statistic which do not lead us to reject the null hypothesis of having drawn a sample from a population with a normal distribution.

The average return reported in Table A.1 is positive for all three currencies' trading period returns and are negative for all three non-trading period returns. The level of standard deviation is remarkably similar (0.45 to 0.55) for all currencies and periods. The level of skewness reported in Table A.1 is negative for all the returns except the non-trading period returns for the Japanese yen and the Deutsche mark. The non-normality of the trading and non-trading period returns for most of the currencies included in this study should not pose a significant problem for the trading/non-trading variance ratios since the ratios of variances, are distributed according to the F-distribution, not the normal distribution.

In table A.2, the auto correlation and cross correlations for one and two period lags are presented for the trading and non-trading periods of each of the currencies. The highest correlation for each of the three currencies is the correlation between the trading period return and non-trading return lagged two periods. The correlations in this case are -.103 for the pound

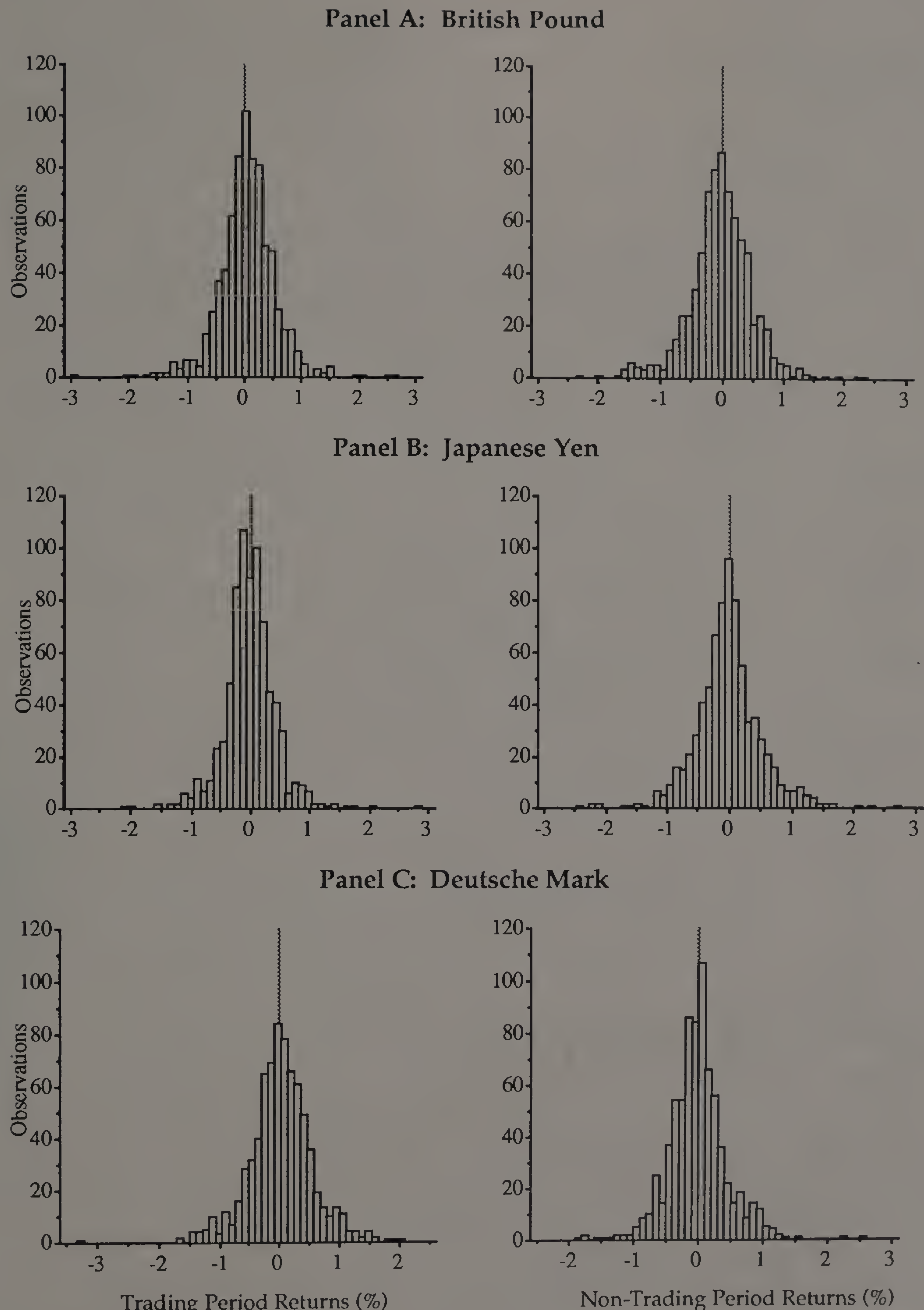

Figure A.1: Distributions of Currency Futures Returns

Table A.1

Currency Futures Returns Descriptive Statistics

	British Pound		Japanese Yen		Deutsche Mark	
	T	NT	T	NT	T	NT
Observations	757	757	757	757	757	757
Mean	.028	-.025	.001	-.015	.024	-.017
Std. Dev.	.506	.508	.465	.543	.525	.453
Skewness	-.171	-.196	-.414	.105	-.211	.307
Kurtosis	4.414	2.498	8.665	2.982	3.024	3.023
W-Statistic	66.754*	12.795*	1033.867*	1.401	5.635	11.908*

The W-statistic test for normality, as presented in Greene (1990; pp. 329) is given by:
$W = n[(skewness)^2/6) + (kurtosis - 3)^2/24] \sim \chi^2(2)$. The 5 percent critical value from the chi-squared table for two degrees of freedom is 5.99, which suggests that all but two of the return distributions depart significantly from normality.

and mark and -.086 for the yen. There does not seem to be a consistent pattern of autocorrelation for the trading period (or non-trading period) return and its own one and two period lagged returns.

Table A.2

Currency Futures Returns
Trading and Non-Trading Period Autocorrelations

Panel A: British Pound

	R(T)	R(T_{-1})	R(T_{-2})	R(NT_{-1})	R(NT_{-2})	R(NT)
R(T)	1.000					
R(T_{-1})	-.037	1.000				
R(T_{-2})	.021	-.031	1.000			
R(NT_{-1})	.054	.050	.054	1.000		
R(NT_{-2})	-.103	.044	.056	.027	1.000	
R(NT)	.054	.047	.018	.038	-.010	1.000

Panel B: Japanese Yen

	R(T)	R(T_{-1})	R(T_{-2})	R(NT_{-1})	R(NT_{-2})	R(NT)
R(T)	1.000					
R(T_{-1})	-.071	1.000				
R(T_{-2})	-.003	-.071	1.000			
R(NT_{-1})	.055	-.013	.080	1.0000		
R(NT_{-2})	-.086	.055	-.013	-.0003	1.000	
R(NT)	-.013	.080	.016	-.0003	.071	1.000

Panel C: Deutsche Mark

	R(T)	R(T_{-1})	R(T_{-2})	R(NT_{-1})	R(NT_{-2})	R(NT)
R(T)	1.000					
R(T_{-1})	-.056	1.000				
R(T_{-2})	.025	-.049	1.000			
R(NT_{-1})	.024	-.039	.041	1.000		
R(NT_{-2})	-.103	.011	-.033	-.029	1.000	
R(NT)	-.035	.029	.015	-.009	.015	1.000

Where: $R(T_{-1})$ is the trading period return lagged one day, $R(T_{-2})$ is lagged two days, and so on.

APPENDIX B

MAXIMUM LIKELIHOOD ESTIMATION

In this appendix the log-likelihood estimators are derived for Models I and III (estimators for Models II and IV are derived by substituting the term $(\sigma_1^2 + \Phi\sigma_2^2)$ throughout for σ_1^2 to obtain the estimator of each model with a conditional variance term). This appendix also presents the actual likelihood estimators used (which are slightly different) and the TSP programs for actually estimating the parameters.

B.1 Derivation of Likelihood Estimators

$$\begin{aligned}
\ln L &= \ln\left\{\prod_{t=1}^{T}\frac{1}{\sqrt{2\pi\sigma_1^2}}\exp\left[-\frac{1}{2}\frac{(x_t-\mu)^2}{\sigma_1^2}\right]\right\} \\
&= \ln\left\{(2\pi)^{-T/2}(\sigma_1^2)^{-T/2}\exp\left[-\frac{1}{2}\sum_{t=1}^{T}\frac{(x_t-\mu)^2}{\sigma_1^2}\right]\right\} \\
&= \ln(2\pi)^{-T/2} + \ln(\sigma_1^2)^{-T/2} - \frac{1}{2}\sum_{t=1}^{T}\frac{(x_t-\mu)^2}{\sigma_1^2} \\
&= -\frac{T}{2}\ln(2\pi) - \frac{T}{2}\ln(\sigma_1^2) - \frac{1}{2}\sum_{t=1}^{T}\frac{(x_t-\mu)^2}{\sigma_1^2}
\end{aligned} \tag{B.1}$$

Taking the log of the products of the joint p.d.f.s gives the log-likelihood function, which is solved in (B.2) below.

$$\ln L = \ln\left\{\prod_{t=1}^{T}\sum_{j=0}^{J} f(x;\lambda)\cdot f(x;\mu,\sigma_1^2,\lambda,\theta,\delta^2)\right\} \tag{B.2}$$

$$= \ln\left\{\prod_{t=1}^{T}\sum_{j=0}^{J}\left(e^{-\lambda}\right)\frac{\lambda^j}{j!}\frac{1}{\sqrt{2\pi(\sigma_1^2+\delta^2 j)}}\exp\left[-\frac{(x_t-\mu-\theta j)^2}{2(\sigma_1^2+\delta^2 j)}\right]\right\}$$

$$= \ln\left\{\prod_{t=1}^{T}\left(e^{-\lambda}\right)(2\pi)^{-1/2}\sum_{j=0}^{J}\frac{\lambda^j}{j!}\frac{1}{\sqrt{(\sigma_1^2+\delta^2 j)}}\exp\left[-\frac{(x_t-\mu-\theta j)^2}{2(\sigma_1^2+\delta^2 j)}\right]\right\}$$

$$= \ln\left(e^{-\lambda}\right)^T + \ln(2\pi)^{-T/2} + \ln\sum_{t=1}^{T}\sum_{j=0}^{J}\frac{\lambda^j}{j!}\frac{1}{\sqrt{(\sigma_1^2+\delta^2 j)}}\exp\left[-\frac{(x_t-\mu-\theta j)^2}{2(\sigma_1^2+\delta^2 j)}\right]$$

$$= -T\lambda - \frac{T}{2}\ln(2\pi) + \ln\sum_{t=1}^{T}\sum_{j=0}^{J}\frac{\lambda^j}{j!}\frac{1}{\sqrt{(\sigma_1^2+\delta^2 j)}}\exp\left[-\frac{(x_t-\mu-\theta j)^2}{2(\sigma_1^2+\delta^2 j)}\right]$$

Equation (B.2) can be rewritten by noting that for the case of $j = 0$, the term after the second summation sign collapses to a much smaller expression, which can be moved outside that summation operator.

$$\ln L = \left(-\frac{T}{2}\ln(2\pi) - \frac{T}{2}\ln(\sigma_1^2) - \frac{1}{2}\sum_{t=1}^{T} - \frac{(x_t-\mu)^2}{\sigma_1^2}\right)$$
$$+ \left\{-T\lambda + \ln\sum_{t=1}^{T}\sum_{j=1}^{J}\frac{\lambda^j}{j!}\frac{1}{\sqrt{(\sigma^2+\delta^2 j)}}\exp\left[-\frac{(x_t-\mu-\theta j)^2}{2(\sigma_1^2+\delta^2 j)}\right]\right\} \tag{B.3}$$

Thus, in this form, it is somewhat more "obvious" that the log-likelihood function is in fact made up of a diffusion process (the term in large parentheses) and a jump process with T = 10 jumps (the term in large braces).

B.2 TSP Programs

In this section, the actual likelihood functions and the TSP programs which operationalize the estimation of the parameters are given.

B.2.1 *Model I*

The log-likelihood estimator for Model I is given by (3.11) and is repeated below.

$$\ln L = -\frac{T}{2}\ln(2\pi) - \frac{T}{2}\ln(\sigma_1^2) - \frac{1}{2}\sum_{t=1}^{T}\frac{(x_t-\mu)^2}{\sigma_1^2} \tag{B.4}$$

The likelihood function which is actually modeled in the TSP program is

$$\ln L = -\frac{1}{2}\ln(2\pi) - \frac{1}{2}\ln(\sigma_1^2) - \frac{1}{2}\frac{(x_t-\mu)^2}{\sigma_1^2}. \tag{B.5}$$

The TSP maximum likelihood sub-routine then maximizes the sum of this function across all observations. The TSP program is given below.

```
OPTIONS CRT; FREQ N; SMPL 1,758;
READ(FILE='A:\DAY-TSP\JYFDAY.PRN')
              DATE,HOL,DAY,US,US1,US2,US3,US4,
              FOR,FOR1,FOR2,FOR3,FOR4,RNT,RT,RDAY;
FRML EQ1 LOGL= -.5*LOG(6.283185)-.5*LOG(V)-((RT-M)**2)/(2*V);

PARAM   M,.01 V,.02;
ML EQ1 ;
```

B.2.2 *Model II*

The log-likelihood estimator for Model II is given by (3.16) and is repeated below.

$$\ln L = -\frac{T}{2}\ln(2\pi) - \frac{T}{2}\ln\left(\sigma_1^2+\Phi\sigma_2^2\right) - \frac{1}{2}\sum_{t=1}^{T}\frac{(x_t-\mu)^2}{\left(\sigma_1^2+\Phi\sigma_2^2\right)} \tag{B.6}$$

The corresponding function used for the TSP program is:

$$\ln L = -\frac{1}{2}\ln(2\pi) - \frac{1}{2}\ln\left(\sigma_1^2+\Phi\sigma_2^2\right) - \frac{1}{2}\frac{(x_t-\mu)^2}{\left(\sigma_1^2+\Phi\sigma_2^2\right)}. \tag{B.7}$$

The TSP program is given below.

```
OPTIONS CRT; FREQ N; SMPL 1,758;
READ(FILE='A:\DAY-TSP.DAT\JYFDAY.PRN')
                DATE,HOL,DAY,US,US1,US2,US3,US4,
                FOR,F,FOR2,FOR3,FOR4,X,RT,RDAY;

FRML EQ1 LOGL= -.5*LOG(6.283185)-.5*LOG(V1*V1+F*V2*V2)
               -((X-M)**2)/(2*(V1*V1+F*V2*V2)) ;

PARAM   M,.003255  V1,.45  V2,0.0 ;
ML (HITER=D) EQ1 ;
```

B.2.3 Model III

The log-likelihood estimator for Model III is given by (3.22) and is repeated below.

$$\ln L = -T\lambda - \frac{T}{2}\ln(2\pi) + \ln\sum_{t=1}^{T}\sum_{j=0}^{J}\frac{\lambda^j}{j!}\frac{1}{\sqrt{(\sigma_1^2+\delta^2 j)}}\exp\left[-\frac{(x_t-\mu-\theta j)^2}{2(\sigma_1^2+\delta^2 j)}\right] \quad \text{(B.8)}$$

The corresponding function used for the TSP program is:

$$\ln L = -\lambda - \frac{1}{2}\ln(2\pi) + \ln\sum_{j=0}^{10}\frac{\lambda^j}{j!}\frac{1}{\sqrt{(\sigma_1^2+\delta^2 j)}}\exp\left[-\frac{(x_t-\mu-\theta j)^2}{2(\sigma_1^2+\delta^2 j)}\right] \quad \text{(B.9)}$$

where the number of jumps per period is truncated at J = 10. The TSP program is given below.

```
OPTIONS CRT; FREQ N; SMPL 1,758;
READ(FILE='A:\DAY-TSP.DAT\JYFDAY.PRN')
                DATE,HOL,DAY,US,US1,US2,US3,US4,
                FOR,FOR1,FOR2,FOR3,FOR4,X,RT,RDAY;

FRML B0  ((L*L)**0)/1;
FRML B1  ((L*L)**1)/1;
FRML B2  ((L*L)**2)/2;
FRML B3  ((L*L)**3)/6;
FRML B4  ((L*L)**4)/24;
FRML B5  ((L*L)**5)/120;
FRML B6  ((L*L)**6)/720;
FRML B7  ((L*L)**7)/5040;
FRML B8  ((L*L)**8)/40320;
FRML B9  ((L*L)**9)/362880;
FRML B10  ((L*L)**10)/3628800;

FRML C0 1/(S*S)**.5; FRML C1 1/(S*S+D*D*1)**.5;
FRML C2 1/(S*S+D*D*2)**.5; FRML C3 1/(S*S+D*D*3)**.5;
FRML C4 1/(S*S+D*D*4)**.5; FRML C5 1/(S*S+D*D*5)**.5;
FRML C6 1/(S*S+D*D*6)**.5; FRML C7 1/(S*S+D*D*7)**.5;
FRML C8 1/(S*S+D*D*8)**.5; FRML C9 1/(S*S+D*D*9)**.5;
FRML C10 1/(S*S+D*D*10)**.5;
```

```
FRML D0  EXP( (-(X-M-TH*0)**2)/(2*(S*S+D*D*0)) );
FRML D1  EXP( (-(X-M-TH*1)**2)/(2*(S*S+D*D*1)) );
FRML D2  EXP( (-(X-M-TH*2)**2)/(2*(S*S+D*D*2)) );
FRML D3  EXP( (-(X-M-TH*3)**2)/(2*(S*S+D*D*3)) );
FRML D4  EXP( (-(X-M-TH*4)**2)/(2*(S*S+D*D*4)) );
FRML D5  EXP( (-(X-M-TH*5)**2)/(2*(S*S+D*D*5)) );
FRML D6  EXP( (-(X-M-TH*6)**2)/(2*(S*S+D*D*6)) );
FRML D7  EXP( (-(X-M-TH*7)**2)/(2*(S*S+D*D*7)) );
FRML D8  EXP( (-(X-M-TH*8)**2)/(2*(S*S+D*D*8)) );
FRML D9  EXP( (-(X-M-TH*9)**2)/(2*(S*S+D*D*9)) );
FRML D10 EXP( (-(X-M-TH*10)**2)/(2*(S*S+D*D*10)) );

FRML E0  (B0*C0*D0);
EQSUB E0 B0 C0 D0;
FRML E1  (B1*C1*D1);
EQSUB E1 B1 C1 D1;
FRML E2  (B2*C2*D2);
EQSUB E2 B2 C2 D2;
FRML E3  (B3*C3*D3);
EQSUB E3 B3 C3 D3;
FRML E4  (B4*C4*D4);
EQSUB E4 B4 C4 D4;
FRML E5  (B5*C5*D5);
EQSUB E5 B5 C5 D5;
FRML E6  (B6*C6*D6);
EQSUB E6 B6 C6 D6;
FRML E7  (B7*C7*D7);
EQSUB E7 B7 C7 D7;
FRML E8  (B8*C8*D8);
EQSUB E8 B8 C8 D8;
FRML E9  (B9*C9*D9);
EQSUB E9 B9 C9 D9;
FRML E10  (B10*C10*D10);
EQSUB E10 B10 C10 D10;

FRML EQ1 LOGL = -(L*L) - .918938533
        + LOG(E0+E1+E2+E3+E4+E5+E6+E7+E8+E9+E10);
EQSUB EQ1  E0 E1 E2 E3 E4 E5 E6 E7 E8 E9 E10;

PARAM  M,.02  S,.29   L,.80  TH,.003  D,.54 ;
ML (HITER=D) EQ1;

END;
```

B.2.4 *Model IV*

The log-likelihood estimator for Model IV is given by (3.25) and is repeated below.

$$\ln L = -T\lambda - \frac{T}{2}\ln(2\pi) + \ln\sum_{t=1}^{T}\sum_{j=0}^{J}\frac{\lambda^j}{j!}\frac{1}{\sqrt{(\sigma_1^2+\Phi\sigma_2^2+\delta^2 j)}}\exp\left[-\frac{(x_t-\mu-\theta j)^2}{2(\sigma_1^2+\Phi\sigma_2^2+\delta^2 j)}\right] \tag{B.10}$$

The corresponding function used for the TSP program is:

$$\ln L = -\lambda - \frac{1}{2}\ln(2\pi) + \ln\sum_{j=0}^{10}\frac{\lambda^j}{j!}\frac{1}{\sqrt{(\sigma_1^2+\Phi\sigma_2^2+\delta^2 j)}}\exp\left[-\frac{(x_t-\mu-\theta j)^2}{2(\sigma_1^2+\Phi\sigma_2^2+\delta^2 j)}\right] \tag{B.11}$$

where the number of jumps per period is truncated at J = 10. The TSP program is given below.

```
OPTIONS CRT; FREQ N; SMPL 1,758;
READ(FILE='A:\DAY-TSP.DAT\BPFDAY.PRN')
DATE,HOL,DAY,US,US1,US2,US3,US4,
FOR,FOR1,FOR2,F,FOR4,X,RT,RDAY;

FRML B0  ((L*L)**0)/1;
FRML B1  ((L*L)**1)/1;
FRML B2  ((L*L)**2)/2;
FRML B3  ((L*L)**3)/6;
FRML B4  ((L*L)**4)/24;
FRML B5  ((L*L)**5)/120;
FRML B6  ((L*L)**6)/720;
FRML B7  ((L*L)**7)/5040;
FRML B8  ((L*L)**8)/40320;
FRML B9  ((L*L)**9)/362880;
FRML B10  ((L*L)**10)/3628800;

FRML C0 1/(S1*S1+F*S2*S2)**.5;
FRML C1 1/(S1*S1+F*S2*S2+D*D*1)**.5;
FRML C2 1/(S1*S1+F*S2*S2+D*D*2)**.5;
FRML C3 1/(S1*S1+F*S2*S2+D*D*3)**.5;
FRML C4 1/(S1*S1+F*S2*S2+D*D*4)**.5;
FRML C5 1/(S1*S1+F*S2*S2+D*D*5)**.5;
FRML C6 1/(S1*S1+F*S2*S2+D*D*6)**.5;
FRML C7 1/(S1*S1+F*S2*S2+D*D*7)**.5;
FRML C8 1/(S1*S1+F*S2*S2+D*D*8)**.5;
FRML C9 1/(S1*S1+F*S2*S2+D*D*9)**.5;
FRML C10 1/(S1*S1+F*S2*S2+D*D*10)**.5;

FRML D0  EXP( (-(X-M-TH*0)**2)/(2*(S1*S1+F*S2*S2+D*D*0)) );
FRML D1  EXP( (-(X-M-TH*1)**2)/(2*(S1*S1+F*S2*S2+D*D*1)) );
FRML D2  EXP( (-(X-M-TH*2)**2)/(2*(S1*S1+F*S2*S2+D*D*2)) );
FRML D3  EXP( (-(X-M-TH*3)**2)/(2*(S1*S1+F*S2*S2+D*D*3)) );
FRML D4  EXP( (-(X-M-TH*4)**2)/(2*(S1*S1+F*S2*S2+D*D*4)) );
FRML D5  EXP( (-(X-M-TH*5)**2)/(2*(S1*S1+F*S2*S2+D*D*5)) );
FRML D6  EXP( (-(X-M-TH*6)**2)/(2*(S1*S1+F*S2*S2+D*D*6)) );
FRML D7  EXP( (-(X-M-TH*7)**2)/(2*(S1*S1+F*S2*S2+D*D*7)) );
```

```
FRML D8  EXP( (-(X-M-TH*8)**2)/(2*(S1*S1+F*S2*S2+D*D*8)) );
FRML D9  EXP( (-(X-M-TH*9)**2)/(2*(S1*S1+F*S2*S2+D*D*9)) );
FRML D10 EXP( (-(X-M-TH*10)**2)/(2*(S1*S1+F*S2*S2+D*D*10)) );

FRML E0  (B0*C0*D0);
EQSUB E0 B0 C0 D0;
FRML E1  (B1*C1*D1);
EQSUB E1 B1 C1 D1;
FRML E2  (B2*C2*D2);
EQSUB E2 B2 C2 D2;
FRML E3  (B3*C3*D3);
EQSUB E3 B3 C3 D3;
FRML E4  (B4*C4*D4);
EQSUB E4 B4 C4 D4;
FRML E5  (B5*C5*D5);
EQSUB E5 B5 C5 D5;
FRML E6  (B6*C6*D6);
EQSUB E6 B6 C6 D6;
FRML E7  (B7*C7*D7);
EQSUB E7 B7 C7 D7;
FRML E8  (B8*C8*D8);
EQSUB E8 B8 C8 D8;
FRML E9  (B9*C9*D9);
EQSUB E9 B9 C9 D9;
FRML E10  (B10*C10*D10);
EQSUB E10 B10 C10 D10;

FRML EQ1 LOGL = -(L*L) - .918938533
+ LOG(E0+E1+E2+E3+E4+E5+E6+E7+E8+E9+E10);
EQSUB EQ1  E0 E1 E2 E3 E4 E5 E6 E7 E8 E9 E10;

PARAM M,-.045  S1,.22  S2,.0001   L,.83  TH,.033  D,.46 ;

ML (HITER=D) EQ1;

END;
```

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